EFFECTS OF SPEAKER AGE ON SPEECH UNDERSTANDING AND LISTENING EFFORT IN OLDER ADULTS

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Abstract

Purpose: Hearing loss is a prevalent condition among older adults. Structural changes at the auditory periphery, changes in central audition and cognitive function are all known to influence speech understanding in older adults. Biological aging also alters speech and voice characteristics from the age of 50 years. These changes are likely to reduce the clarity of speech signals received by older adults with age-related hearing loss. Recent findings suggest that older adults with hearing loss subjectively find listening to the speech of other older adults more effortful than listening to the speech of younger adults. However, the observations of listener effort were subjective and follow up using an objective measure was recommended. Therefore, the purpose of this study was to determine the influence of speaker age (young versus older) on speech understanding and listener effort in older adults with hearing loss. In addition, the relationships between these parameters, and age and working memory was investigated. It is hypothesised that older adults with hearing loss will recognise less speech, and expend more effort, while listening to speech of an older adult relative to a younger adult.

Method: A dual task paradigm was used to measure speech understanding and listening effort in 18 older adult listeners with hearing loss. The primary task involved recognition of target words in sentences containing either high or low contextual cues. The secondary task required listeners to memorise the target words for later recall following a set length of sentences. Listeners performed speech understanding (primary task) under six experimental conditions: For each speaker (i.e., older adult and younger adult) there were 3 listening backgrounds: quiet, and noise at 0 dB SNR and +5 dB SNR.

Results: Speech understanding in older adults with hearing loss was significantly improved when the speaker was an older adult, especially in noise. The ability to recall words from memory was also significantly better when the speaker was an older adult. Age was

strongly correlated with speech understanding with contributions from hearing loss. Age and working memory had moderate correlations with word recall.

Conclusion: The findings provide further evidence that peripheral hearing loss is not the only contributor to speech understanding and word recall ability in older adults. The naturally occurring speech signal also has the potential to influence speech understanding and listening effort in older adults.

Introduction

Prevalence of Age-Related Hearing Loss

Hearing loss is widespread among the elderly (Cruickshanks et al., 1998). According to the World Health Organisation (WHO), hearing loss ranks within the ten leading causes of mortality and disease burden in adults aged over 60 years (WHO, 2003), consistent with reports that hearing loss is more common than heart disease for this age group (Adams, Hendershot, & Marano, 1999). Estimates of the general population of adults aged over 60 years with hearing loss vary from 19.5% (Greville, 2001, 2005) to approximately 55% (Cruickshanks, et al., 1998), and extend to as much as 87.1% of those in institutional care (Flynn, Kennedy, Johns, & Stanbridge, 2002).

The variation in reported prevalence appears to result from differences between investigations in their approach to assessing the presence of hearing loss. Population based studies have typically measured hearing loss using either audiometric procedures (Cruickshanks, et al., 1998; Gates & Cooper, 1991; Gates, Cooper, Kannel, & Miller, 1990), or census data to estimate the proportion of individuals with self-reported hearing loss (Adams, et al., 1999; Dillon, Gu, Hoffman, & Ko, 2010; Greville, 2001, 2005).

Where standard audiometric testing has been used, the differences in reported prevalence may be explained by inconsistent hearing threshold criteria used across studies. For example, 29% of adults over 60 years of age from the Framingham Heart Cohort were defined as having a hearing loss when their pure-tone threshold average (PTA) at 0.5, 1, and 2 kHz exceeded 26 dB HL for the better ear (Gates, et al., 1990). This figure, however, could underestimate the true proportion of older adults with hearing loss as older adults tend to have poorer hearing sensitivity for higher frequency stimuli relative to the PTA. To support this, individuals in the Beaver Dam (Wisconsin) population were considered to have hearing loss if they had a PTA over 0.5, 1, 2, and 4 kHz that was greater than 25 dB HL in the poorer ear (Cruickshanks et al., 1998). By this criterion, the data indicated that more than half (~55%) of those aged 60 years and over had hearing loss (Cruickshanks, et al., 1998).

The discrepancy in the reported prevalence of hearing loss among older adults has not been improved by population based surveys. For example, hearing loss was shown to affect 27.0% of non-institutionalised adults over 65 years following a census of 7000 New Zealand households (Greville, 2001). Whilst this statistic was agreeable with estimates reported for larger population surveys conducted in the United States (e.g., Adams, et al., 1999), revised questionnaires have resulted in a downgrade of this figure to between 19.5% and 22.1% (Greville, 2005).

Differences in methodologies across studies have precluded precise estimates of hearing loss prevalence among the elderly. Despite the uncertainty with respect to the number of older adults with hearing loss, it expected that the ratio of New Zealander's living beyond the age of 65 years will increase from one in eight persons in the year 2009 to one in five by 2031 (Ashley-Jones, 2009). Given this future trend, the number of older adults with hearing loss will continue to increase. As such, it is important to understand the challenges older adults experience during typical, everyday communication situations so that appropriate rehabilitation options may be developed.

Age-related Changes to the Pure-tone Audiogram

Senescent changes that reduce the audibility of frequencies important for speech have been documented extensively. In measuring these changes, investigators have attempted to tease out extraneous factors such as excessive noise exposure, otologic disease, ototoxicity and other pathologies known to influence hearing (Demeester et al., 2009; Pearson et al., 1995). The effects of biological age on the pure-tone audiogram are inconclusive, however, as exposure to one's environment and concomitant declines in other areas of health suggest that hearing loss over time is multifactorial (Gates & Mills, 2005). As such, the clinical term ‘presbycusis’ is used to describe older adults with hearing loss as a result of age, genetic susceptibility, systemic disease, ototoxicity, and noise exposure (Arlinger, 1990; Gates & Cooper, 1991; Gates, et al., 1990; Liu & Yan, 2007; Tarnowski, Schmiedt, Hellstrom, Lee, & Adams, 1991).

Remarkably, similar trends in the degree and configuration of pure-tone hearing loss in older adults have been reported across studies despite differences in participant inclusion criteria (Arlinger, 1990; Demeester, et al., 2009; Gates, et al., 1990; Pearson, et al., 1995). In one study, Gates et al. (1990) collected audiometric data from 676 males and 986 females ranging in age from 63 to 93 years. This included over one third (38%) of participants with evidence of either middle ear, congenital, noise induced, or asymmetric hearing losses. Air conduction measures demonstrated a continuous increase in pure-tone thresholds, bilaterally, as a function of age with hearing sensitivity poorer for frequencies above 1000–2000 Hz. Furthermore, multivariate analysis revealed older males to have greater threshold levels for high frequencies in comparison to females.

Gates et al. (1990) attributed the gender bias found in their study to the proportion of men exposed to toxic noise levels, however, similar patterns of hearing loss were later seen in studies employing more stringent participant inclusion criteria (Demeester, et al., 2009; Pearson, et al., 1995). For example, Demeester et al. (2009) recruited residents of Antwerp to document the most frequent audiometric patterns for 55 to 65 year old adults. Participants were rigorously screened to exclude non-senescent hearing impairments, and participants were subsequently grouped according to degree of noise-solvent exposure. Final data analysis for 598 females and 549 males revealed three dominant audiometric configurations for this group: flat (37%), high frequency gently sloping (35%), and high frequency steeply sloping (27%) audiograms. The appearance of flat hearing losses was significantly more prevalent in the female participants. On average, however, the age-specific audiograms documented by Demeester et al. (2009) revealed a familiar trend; specifically, pure-tone thresholds increased as a function of age with poorer hearing sensitivity for frequencies above 1000 Hz. Once more, high frequency hearing loss patterns were more prevalent in the male participants, however, these patterns were observed in men with and without high levels of noise-solvent exposure.

The variability in audiometric patterns found by Demeester et al. are consistent with the range in hearing thresholds for octave frequencies between 500 and 4000 Hz found among the older adult population (Morrell, Gordon-Salant, Pearson, Brant, & Fozard, 1996). Collectively, these studies support the notion that age-related hearing loss is the result of various biological factors including genetic differences. Evidence in support of genetic susceptibility has been derived from studies demonstrating a range of evoked hearing thresholds among lower order species raised in quiet (Popelar, Groh, Pelanova, Canlon, & Syka, 2006; Tarnowski, et al., 1991).

Presbycusic hearing losses are commonly associated with the later stages of life; however, age-related declines in hearing acuity have emerged from a relatively young age. Repeated measures of hearing sensitivity in adults between 17 and 90 years have shown that the onset of hearing loss begins in the third decade of life (Pearson, et al., 1995). These measures have also confirmed that for every ten year increase, hearing loss declines more rapidly for stimulus frequencies above 1000 Hz, with a rate of progression that is twice as fast in men compared to women (Pearson, et al., 1995).

Despite the variability in older adults with senescent hearing loss, the audiometric patterns for this group are fairly consistent. That is, declines in hearing sensitivity in old age are largely manifest in the pure-tone audiogram for frequencies above the range of 1000-2000 Hz. This bilateral, sloping sensorineural hearing loss has practical implications for speech understanding as the overall intensity of the speech spectrum is heard at lower sensation levels by individuals with hearing loss, compared to listeners with normal hearing (Humes, 1991). Furthermore, the contour of hearing loss typical to presbycusis limits the available bandwidth of high frequency consonant sounds, which in turn has negative consequences for speech perception (Dubno & Dirks, 1989; Dubno, Dirks, & Schaefer, 1989; Hornsby & Ricketts, 2006).

Speech Understanding and Aging

The term speech understanding can be used to describe various perception tasks including discrimination, identification, recognition, or comprehension of speech (Humes, 1996; Humes et al., 1994). Auditory speech understanding is a complex process shared between bottom-up sensory mechanisms and top-down cognitive control (Webster, 1999). As demonstrated in one model (e.g., Davis, 1964), the acoustic properties of the speech are encoded by the auditory periphery for central conduction; lateralization and feature extraction of the signal is performed during early stages of central auditory processing, followed by integration and re-synthesis. Over the course of bottom-up processing, cognitive resources attend to the stimulus, and integrate the encoded signal with stored knowledge of language to transfer speech into meaning.

Age-group comparisons and repeated measures of auditory function have revealed that speech understanding is inversely related to age for a variety of speech perception stimuli (Divenyi, Stark, & Haupt, 2005; Dubno et al., 2008; Gates, et al., 1990). Whilst age-related declines in hearing sensitivity are a likely cause of this observation (Dubno, Lee, Matthews, & Mills, 1997; Gates, et al., 1990), the rate and variability of speech understanding decline with age is greater, compared to the rate of hearing threshold decline (Divenyi, et al., 2005). Furthermore, once speech has been spectrally shaped to improve audibility, individual differences in word recognition become apparent between older adults with similar degrees of hearing loss (Humes, 2007). Taken together, these findings suggest that factors beyond elevated pure-tone thresholds also contribute to speech understanding in older adults.

Numerous hypotheses have been advanced to explain what factors influence speech understanding in older adults (Pichora-Fuller & Singh, 2006). Following an extensive review of auditory and cognitive aging literature, an article prepared by the Working Group on Speech Understanding and Aging (CHABA, 1988) reported that everyday speech understanding is susceptible to senescent changes in one or more of the following processes: peripheral audition, central audition, and cognitive function. In the review of speech perception studies that follow, a number of investigators have found that speech understanding in older adults is largely constrained by declines in audition, with subsequent declines in cognitive performance (Akeroyd, 2008; Humes, 1996, 2007; Pichora-Fuller & Singh, 2006).

In addition to the framework provided by CHABA (1988), processing models also demonstrate that perceived declines in cognition among older adults may be a consequence of age related declines in sensory processing (Ronnberg, Rudner, Foo, & Ludner, 2008). For example, poor encoding in an aging auditory system increases the level of cognitive effort expended by older adults to correctly understand speech (Pichora-Fuller, 2003; Arlinger, Lunner, Lyxell & Pichora-Fuller, 2009). The relative amount of cognitive effort needed during speech understanding has been quantified in previous research using a method that requires listeners to carry out a speech perception activity while performing a simultaneous task (Gosselin & Gagne, 2010). As such, a similar procedure will be adopted here to assess the effect of an older adult and younger adult speakers' voice on both speech understanding and cognitive effort levels of older listeners with hearing loss.

Peripheral Auditory Hypothesis

The peripheral auditory hypothesis suggests that speech understanding difficulties in older listeners arise from declines in sensory processing at the level of the cochlea, or spiral ganglion cells of the auditory nerve, due to structural and functional changes at the auditory periphery (Humes, 1996; Pichora-Fuller & Singh, 2006). Such changes are expressed in the pure-tone audiogram as elevated hearing thresholds and reduced dynamic range (For reviews see: Chisolm, Willott, & Lister, 2003; Gates & Mills, 2005; Liu & Yan, 2007).

Assuming peripheral hearing loss is the sole cause of speech understanding difficulties in older listeners, both young and older adults with similar limitations in audibility should perform equivalently on speech perception tasks. For example, Humes and Roberts (1990) compared speech understanding between older listeners with hearing loss and two groups of young listeners with either normal hearing, or monaural hearing loss simulated by spectral masking. Speech recognition was measured for nonsense syllable stimuli altered temporally, and presented in quiet or in noise. As expected, listeners with reduced audibility achieved significantly lower speech understanding scores than listeners with normal hearing. Furthermore, speech understanding scores for older listeners with hearing loss and young adults with simulated hearing loss were not significantly different. The latter outcome was proposed to be the result of reduced audibility for high frequency components of the test materials. Humes and Roberts also reported a strong negative relationship between speech understanding scores and degree of hearing loss, assigning 80% of the variation in speech understanding scores to differences in the PTA at 1, 2, and 4 kHz.

That older listener's speech understanding performance can be accounted for by declines in audibility has also been supported by subsequent behavioural studies. For example similar group differences have been found for speech perception tasks using either: synthetically processed monosyllabic words (Humes, et al., 1991), and filtered and temporally processed syllables (Humes & Christopherson, 1991). Collectively, these studies showed that when audibility is reduced for young healthy adults with essentially no declines in central audition or cognition, their speech understanding abilities were similar to the older adult participants with hearing loss.

The link between peripheral auditory processing declines and speech understanding in older listeners is further evidenced by studies comparing different age groups with equivalent, biological hearing losses. For example, Souza & Turner (1994) measured speech understanding for monosyllables presented in a variety of background noises and found no significant difference between the group mean scores of older adult listeners and younger adult listeners closely matched for sensorineural hearing loss. Similarly, Dubno, Lee, Matthews, and Mills (1997) tested the speech understanding abilities of three different age cohorts (55-64, 65-74, 75-84) closely matched for audiometric frequency thresholds. The average speech understanding scores for a variety of test materials (monosyllable words, synthetic sentences, and low- and high-context sentences) were similar across groups.

While it appears that the speech understanding abilities of older adults are dominated by senescent declines in audibility, the aforementioned perceptual studies were largely conducted under monaural listening conditions, used simple speech stimuli, and were dependent on the availability of high frequency acoustic cues. In reality, listening to speech is typically dependent on the central synthesis of binaural input (Davis, 1964). Furthermore, everyday discourse is more complex than perfectly articulated words or short phrases (CHABA, 1988). Hence, successful speech understanding in older adults is often constrained by their ability to benefit from the redundancies in the speech signal including syntactic and semantic cues (Pichora-Fuller, 2008; Sheldon, Pichora-Fuller, & Schneider, 2008)

According to the literature reviewed here, as much as 20- to-50% of the variation in speech perception scores in older adults is not due to loss of audibility alone (Humes & Christopherson, 1991; Humes, et al., 1991; Humes & Roberts, 1990). This suggests that speech understanding in older adults is also influenced by factors central to peripheral hearing loss.

Central Auditory Hypothesis

The central auditory hypothesis implies that information encoded at the periphery is conveyed to higher centres less accurately as a result of processing errors in one or more stages of central audition (CHABA, 1988; Chisolm, et al., 2003; Humes, 1996).

Deficits in central auditory processing are not readily apparent from the standard pure-tone audiogram. Furthermore, tests developed to assess an auditory disorder are lacking a gold standard (British Society of Audiology, 2011). According to one definition, however, support for the central auditory hypothesis may be derived by comparing clinically normal hearing adults, at opposite ends of the age spectrum, on speech perception tasks in complex listening conditions (American Speech-Language-Hearing Association, 2005). In this context, 'complex' refers to the ability to understand speech that has been degraded by background noise, temporal distortion, or both.

For example Helfer and Wilbur (1990), compared recognition for nonsense syllables across four different listening groups: young adults with normal hearing or hearing loss, and older adults with near-normal hearing or presbycusis. The speech stimuli used in that study were presented binaurally under complex listening conditions. Analysis of the group data demonstrated that young adult listeners with normal hearing outperformed older adults with minimal hearing loss across all conditions including quiet. Furthermore, older listeners with and without hearing loss achieved similar scores for reverberant speech heard in quiet, as well as mild degrees of reverberation heard in noise. From partial correlation analysis, the investigators found that 'age' in addition to loss of audibility, also accounted for the discrepancy in speech understanding between young and older adults when listening to speech in under a variety of conditions.

Conversely, Helfer (1992) later reported similar speech understanding scores between older adults with near normal hearing and younger healthy adults for complex stimulus materials. On average, the older adults performed more poorly, to the younger adults for seven out of eight listening conditions. Despite the conflicting results between both Helfer and Wilber (1990) and Helfer (1992), once loss of audibility was minimised, older adult individuals continued to perform more poorly on tasks of speech understanding indicative of age factors beyond peripheral hearing loss. One such factor may involve structural and function changes to the central auditory system as a direct result of biological aging or indirect result of sensory deprivation (Chisolm et al., 2003). For a discussion of these age-related changes and the implications for central audition see Golding (2007) and Lagace, Jutras and Gagne (2010).

Further support for the central auditory hypothesis has also emerged from behavioural studies controlling for hearing loss and cognition (Frisina & Frisina, 1997; Gordon-Salant & Fitzgibbons, 1993; Jerger, Jerger, Oliver, & Pirozzolo, 1989). Gordon-Salant and Fitzgibbons (1993), reported similar levels of recognition of speech in quiet for low-predictability sentences between normal hearing young and older adults. Discrepancies between these groups later emerged when the speech signal was more complex. Specifically, older adults recognised less words that were temporally distorted compared to the younger adults, consistent with the previous findings of Helfer and Wilbur (1990). Furthermore, the group scores overlapped between the normal hearing older adults and the younger adults with hearing loss (Gordon-Salant & Fitzgibbons, 1993). Because the older adults in that study were required to pass a cognitive screen, deficits in central audition may have reduced word recognition accuracy in some participants when listening to temporally degraded speech.

Age-related processes beyond peripheral hearing loss were also found in another study by Frisina and Frisina (1997). They reported similar performances between groups of normal hearing young and old adults on tasks of speech perception for spondees, or high- and low-context sentences in quiet. However, when speech was presented in a background of babble, older adults generally required a more favourable SNR compared to that of the younger adults. Because greater benefit from supportive context was observed in older adults compared to younger adults, the investigators ruled out underlying cognitive deficits in language processing among the older participants. As such, Frisina and Frisina suggested that differences understanding speech in noise between young and older adults were due to senescent changes in central audition. The finding that older adults are cognitively adept at using supportive context, despite less accuracy for speech perception compared to younger adults, is consistent with other auditory-aging research (Gordon-Salant & Fitzgibbons, 1997; Pichora-Fuller, Schneider, & Daneman, 1995; Sheldon, et al., 2008).

Senescent changes in the central auditory nervous system could explain why some older adults with clinically normal hearing achieve unexpectedly poorer scores on tasks of speech perception in challenging listening conditions. This may also extend to *other* older adults with hearing loss.

Cognitive Aging Hypothesis

Memory and mental processing are necessary for everyday speech understanding (CHABA, 1989). Whilst the evidence presented thus far suggests that speech understanding in older adults is dependent on senescent declines in audition, performance on a variety of cognitive tasks also indicate that declines in higher level functions should be considered (Akeroyd, 2007). Changes in cognition are known to occur with age (Craik & Salthouse, 1992), including changes to functions with central roles in speech understanding such as processing speed and working memory (Craik; 1994; Kemper, 1992). Working memory is conceptualised as a mental workspace for the dual processing and temporary storage of instantaneous inputs (Baddeley, 1992; de Fockert, 2005), and plays a role in the allocation of attentional resources during perceptual activities (Awh & Jonides, 2001). By retaining input from the auditory system long enough for successful integration, and suppressing irrelevant information, the processes that underlie working memory are conducive to tasks of speech understanding.

Some of the variation observed in older adults could be attributable to declines in higher level processing and integration of continuous speech, as individual differences in working memory are believed to exist (Just & Carpenter, 1992). Manipulation and recall of objects such as visual patterns or verbal digits are considered tasks of working memory (Crowe, 2000; de Fockert, 2005; Humes & Floyd, 2005), and have been used in a number of speech perception studies for subsequent correlation analysis (Akeroyd, 2008). For example, Humes and Floyd (2005) measured working memory capacity in young adults and older adults with hearing loss using the Simon Memory-Learning Game delivered in auditory-only, visual-only and auditory-visual modalities. Regardless of stimulus modality, the results of the memory-learning tasks were superior for the younger participants compared to the older participants. This could suggest that older adults have reduced working memory capacity with which to store and process running speech, thus compromising speech understanding. Whilst Humes and Floyd (2005) found significant relationships between performance on the memory-learning tasks and speech understanding for the older adults, these correlations were relatively weak.

Similarly, reports from a series of experiments suggested that performance on cognitive measures including digit span were related to speech perception in older adults with hearing loss (van Rooij & Plomp, 1990). In a final analysis, however, it was concluded that almost all of the variance in speech perception scores for those older adults under investigation could be explained by differences in the pure-tone audiogram, and thus, loss of audibility (van Rooij & Plomp, 1992).

Beyond correlation between discrete cognitive abilities and speech understanding performance, tasks that require manipulation of complex speech stimuli may be more effective in demonstrating senescent changes in cognitive function such as working memory. One study by Stewart and Wingfield (2009) measured recognition for monosyllable words, subject-relative sentences, and object-relative sentences in both young healthy adults, and older adults with hearing loss or 'better' hearing. As hypothesized, the sound level needed to achieve equivalent scores for each of the speech stimuli in quiet increased with age and hearing loss. Furthermore, the difference in sound level needed to equate scores across the three stimulus materials was greater for both older adult groups compared to the younger adults. From those results, it was interpreted that older adults engage in more effortful listening as the redundancy cues in speech – or as the stimulus complexity increases. In contrast, young adults were likely to expend the same amount of effort regardless of stimulus complexity. Because the older listeners achieved relatively poorer scores on pre-experimental measures of cognitive function, Stewart and Wingfield suggested foremost that increased listening effort in older adults was largely the result of poorer working memory and reduced inhibitory skills. These results were consistent with previous findings by Gordon-Salant and Fitzgibbons (1997) who found that the added memory component needed to recognize and recall sentences without context resulted in poorer accuracy by the older adults in their study, despite slowing the presentation rate.

Whilst age-related declines in memory may contribute to speech understanding abilities in older adults (Gordon-Salant & Fitzgibbons, 1997; Stewart & Wingfield, 2009), poor auditory processing could also lead to poor performances in cognitive (i.e., memory) tasks (Ronnberg et al., 2003; Tun, McCoy, Wingfield, 2009). The ability to recall items from auditory memory has been shown to be similar between older adults with hearing loss and younger adults with noise masked thresholds (Murphy, Craik, Li & Schneider, 2000). Thus, processing efficiency at the cognitive level in older adults may be reduced due to the increase in effort expended to recover speech degraded by poor audition (Pichora-Fuller, et al., 1995). For example, McCoy et al. (2005) presented strings of words varying in contextual constraint to two groups of older listeners differing in hearing acuity. Whilst older adults with hearing loss were able to recognize speech, and recall highly related words from memory as equally well as their better hearing counterparts, they were significantly less efficient at recalling unrelated words from memory. Because both groups of listeners were matched for age, education and verbal vocabulary abilities, this implied that the older adults with hearing loss applied more effort to accurately recognise unrelated continuous speech due to poor auditory processing. As such, declines in audition may have also affected the performance of the older adults under investigation by Stewart and Wingfield (2009) as the hearing sensitivity of the 'better' hearing older adults were significantly different (poorer) to the younger adults in that study. Furthermore, performance among the older adults may have been compounded by changes in central audition, leading to an increase in the expenditure of effort.

In summary, listening in pristine conditions to facilitate speech understanding, such as those employed by Stewart and Wingfield (2009), and McCoy et al. (2005) are not typical of everyday listening conditions. Some degree of ambient noise is nearly always present (Olsen, 1998). Whilst the physical properties and nature of background noise can vary, background noise often consists of the speech of other talkers Agus, Akeroyd, Noble, & Bhullar, 2009; Feston & Plomp, 1990).

Background Noise and Speaker Aging

Background Noise

A number of investigators have documented the disproportionately poorer speech perception accuracy of older adults while listening in the presence of background noise (Divenyi, et al., 2005; Frisina & Frisina, 1997; Gordon-Salant & Fitzgibbons, 1997, 2004; Helfer, 1992; Helfer & Freyman, 2008; Helfer & Wilber, 1990; Humes, Burk, Coughlin, Busey, & Strauser, 2007; Humes & Roberts, 1990; Pichora-Fuller, et al., 1995; van Rooij & Plomp, 1990; van Rooij, Plomp, & Orlebeke, 1989; Wilson et al., 2010). Modulated background noises such as multi-talker babble can negatively impact speech understanding in both normal hearing and hearing impaired adults (Bronkhorst & Plomp, 1992; Duquesnoy, 1983; Feston & Plomp, 1990; Van Engen & Bradlow, 2007). In addition to reducing audibility of the primary speech signal, competing speech in the surrounding environment may prevent listeners from distinguishing the target when the signal and noise are closely matched in spectral and temporal composition (Brungart, Simpson, Ericson, & Scott, 2001). As such speech like noise can mask the primary speech signal on a peripheral and central level (Hornsby, Ricketts & Johnson, 2006), and has been shown to be more detrimental to speech understanding in listeners with hearing loss (Helfer & Freyman, 2008; Souza & Turner, 1994).

Central masking effects are also observed when background noise contains meaningful speech. When Larsby et al. (2008) tested older adults' speech understanding in noise; their results suggested that greater numbers of background talkers are likely to reduce audibility of the target signal in poor listening conditions. As well, their results indicated that fewer background speakers are a potential distraction for older listeners in better conditions. The results of this study provided further evidence that background noise consisting of speech has the ability to mask at both the auditory and cognitive level in older adults.

In addition to the measures of speech perception, Larsby et al. (2008) asked participants to rate their amount of perceived listening effort for the stimuli presented. Despite achieving similar speech understanding scores for SNRs of 0 dB and +5 dB, participants rated the poorest signal to noise ratio as requiring significantly more listening effort to interpret the speech stimulus. Furthermore, variability in perceptual rating scores between listeners also suggested that older adults with similar audiometric hearing losses apply different amounts of cognitive resources during speech understanding in similar listening conditions.

It is clear that the surrounding auditory environment is an important consideration in the examination of the speech perception and effort levels required by older listeners in communication. However, the speech signal itself is also an important consideration as everyday conversational speech is prone to some form of spectral and, or temporal distortion (CHABA, 1988). To date, auditory-aging research has employed a variety of techniques that result in filtered, compressed, extended, interrupted, reverberated, synthesized, or noise-vocoded speech (Amos & Humes, 2007; Arlinger, 1990; Divenyi, et al., 2005; Gordon-Salant & Fitzgibbons, 1997; Humes, et al., 2007; Humes, et al., 1991; Schmitt & Moore, 1989; Schneider, Daneman, & Murphy, 2005; Sheldon, et al., 2008; Vaughan & Letowski, 1997). These studies have been instrumental in documenting the speech perception abilities of older adults, and how they vary depending on the characteristics of the signal itself. However, investigators have overlooked the effects of degraded speech signals that occur *naturally* in many listening environments. One such signal is that of the aging voice. Because older adults are expected to engage in daily communication with peers of similar age, assessing the effects of speaker aging on speech understanding in this population has high ecological validity.

Speaker Aging

The speech signal of older adults is measurably different in its acoustic and perceptual voice characteristics to that of younger adults (Ptacek & Sander, 1966; Ryan & Burk, 1974; Xue & Deliyski, 2001). Such differences enable listeners to distinguish younger adult voices from older adult voices with a high degree of accuracy (Ptacek & Sander, 1966). The features of speech and voice of those over 50 years reflect senescent changes in the systems directly involved in speech production (Ramig et al., 2001; Verdonck-de Leeuw & Mahieu, 2004), as well as declines in neuromuscular control (Ryan & Burk, 1974) and reductions in auditory feedback (Liss, Weismer, & Rosenbek, 1990). Compared to younger adults, the speech and voice of older adults can be described as slower (Liss, et al., 1990), more breathy (Gorham-Rowan & Laures-Gore, 2006; Linville, 2002), rough (Verdonck-de Leeuw & Mahieu, 2004), different in pitch (Nishio & Niimi, 2008; Torre & Barlow, 2009), and degraded by spectral noise (Ferrand, 2002; Harnsberger, Brown, Shrivastav, & Rothman, 2010; Linville, 1996; Ramig & Ringel, 1983). Furthermore, older adult speakers routinely produce more consonant errors (Ryan & Burk, 1974).

Longitudinal investigation of speech changes with age have revealed that significant changes in voice quality can be observed over a relatively short period of time – for example, five years (Verdonck-de Leeuw & Mahieu, 2004). These findings, together with studies that have compared healthy older speakers to both younger adults and those with neurologically-based speech disorders, have demonstrated that the speech and voice quality declines with age. For example Wang, Kent, Kent, Duffy and Thomas (2009) performed an acoustic analysis of voice in groups of adult patients with dysarthria, healthy young adults, and healthy older adults. The results of this investigation showed that healthy older adults had significantly different (poorer) values on at least 10 out of the 15 acoustic parameters assessed compared to the younger adults. This analysis also revealed a positive relationship between age and spectral noise levels in vocal output, consistent with the earlier findings of Xue and Deliyski (2001) who used identical measures to compare healthy older adults to published norms for young and middle-aged adults.

Furthermore, Wang et al. (2009) found similar results between the healthy older speaking, and dysarthria groups on 14 out of the 15 acoustic measures that included indices of voice turbulence and noise-to-harmonic ratio. The average age of the healthy older adults in that study was greater than the dysarthric group leading to the interpretation that both age and dysarthria may exhibit similar acoustic profiles. Further similarities between older adult speakers and pathological speakers (i.e., Parkinson's disease), and the presence of measurable noise in the speech signal, were also reported by Liss et al. (1990) following analysis of selected acoustic characteristics in 22 healthy male speakers over 85 years.

Inherent noise, production errors (Ferrand, 2002; Harnsberger, et al., 2010; Linville, 1996; Ramig & Ringel, 1983; Verdonck-de Leeuw & Mahieu, 2004), and an overlap of characteristics between older adult speakers and pathological speakers (Darley, Aronson, & Brown, 1969) ultimately combine to create a natural distortion of the speech signal. As adults are often engaged in conversational discourse with similar aged peers, it is reasonable to expect that vocal aging may have a negative effect on speech understanding in older adult listeners with hearing loss. Indeed, Torre and Barlow (2009) suggested that voice onset times in older adults may obscure phonemic contrasts and potentially compromise speech understanding in this population.

On this basis investigators have begun to measure the effects of the senescent voice on speech understanding in older listeners. Wilding (2010) presented a selection of high- and low-context sentences, produced by older adult and younger adult speakers to 19 older adults with hearing loss. In this study, speaker age did not differentially affect speech understanding;

however, these results were obtained in quiet and may not reflect true performance in typical, complex listening conditions consisting of background noise. While this was the case, results from a perceptual rating task indicated that participants perceived that they expended greater levels of listening effort when listening to older speakers compared to the younger speakers. From the latter finding, Wilding suggested that older adults with hearing loss may engage more processing or attentional resources when listening to older adult speakers, compared with younger adult speakers, to offset any differences in speech understanding. Based on the findings of the investigation by Wilding (2010), and the limitations of that work, a more detailed investigation of the effects of speaker age on both speech understanding and listener effort – in varied levels of noise and including objective examination of effort – is warranted.

Listening Effort

Hearing provides a sensory awareness of sound including speech, however, listening facilitates communication by attending to incoming sounds (Kiessling et al., 2003). When the speech signal is highly redundant and complemented by visual cues, listening is a relatively easy task (Fraser, Gagne, Alepins, & Dubois, 2010; Larsby, et al., 2008). However, when speech is distorted by background noise or poor internal processing, listeners must focus attentively and apply their knowledge of language for perceptual success (Larsby, et al., 2008; McCoy, et al., 2005; Pichora-Fuller, et al., 1995; Sarampalis, Kalluri, Edwards, & Hafter, 2009). As such, the amount of top-down, cognitive resources invested by a listener to interpret degraded auditory signals can be described as listening effort (Downs & Crum, 1978).

Self-report measures have been employed in previous investigations to assess the degree of listening effort expended (e.g., Larsby, et al., 2008; Wilding, 2010). Using this method, listeners indicated, on an analog scale, how much effort they believed was invested during speech perception tasks. Whilst an increase in perceived listening effort was associated with task difficulty in those participants, this could differ to amount of cognitive resources expended (Zekveld, Kramer, & Feston, 2010). As such, previous reports have demonstrated that subjective measures of listening effort do not always agree with the amount of cognitive resources used for successful speech perception using objective measures (Feuerstein, 1992; Anderson Gosselin & Gagne, in press), particularly when listening conditions become very difficult (Fraser et al., 2010). Furthermore, the validity of self-report measures in older adults can be problematic as this population tend to downplay their degree impairment and thus misjudge their level of performance (cf. Gosselin & Gagne, 2010). Following an extensive review of previous studies, and an investigation of their own, Gosselin and Gagne (2010; Anderson Gosselin & Gagne, in press) have demonstrated the value of employing a dual-task objective procedure to quantify listener effort in older adults.

Objective Measures of Listener Effort

The dual-task paradigm has been used to measure listening effort in a number of auditory-cognitive investigations (Anderson Gosselin & Gagne, in press; Downs, 1982; Downs & Crum, 1978; Feuerstein, 1992; Fraser, et al., 2010; Sarampalis, et al., 2009; Tun, McCoy, & Wingfield, 2009). When using the dual-task paradigm, listeners were encouraged foremost to recognise stimulus target words. At the same time, listeners were asked to complete a secondary task that measured performance for either the number of items recalled from memory, the time to react to a stimulus, or the ability to identify the pattern of a non-auditory stimulus.

For example, Feuerstein (1992) measured word recognition in young adults with simulated monaural hearing losses whilst they were simultaneously engaged in a probe-reaction time task. The results of this study showed that the speech perception scores in the monaural listening mode were significantly lower compared to the binaural listening mode across a variety of difficult auditory conditions. Moreover, the reaction time to the probe light was not significantly different between the binaural and monaural listening modes when noise was directed away from the better hearing ear. From these findings it was interpreted that similar amounts of cognitive effort were applied to both listening conditions. In contrast, when noise was presented to the better hearing ear, and speech was directed toward the occluded ear, participant's reaction times to the probe light were significantly longer. From the latter finding it was interpreted that the significantly delayed reaction time was associated with the increased cognitive effort expended to process the degraded speech stimulus. However, the additional effort expended in this case did not help improve speech understanding for the target words.

As demonstrated in the study by Feuerstein (1992), performance on a separate, simultaneous task (e.g., probe reaction time) was measured to assess the amount of effort expended to process the degraded speech stimulus. This method of analysing effort follows the concept of a working memory store with limited capacity for perceptual processing (Kahneman, 1973). For example, in the limited capacity model, the amount of cognitive resource allocated to a perceptual task increases relative to processing difficulty (i.e., from listening to speech in quiet, to listening to speech in noise). Therefore, as the upper limits of overall capacity are approached, perceptual processing slows (e.g., Fraser et al., 2010) and may result in performance decline. When demand for resources is low (i.e., listening in quiet) spare capacity is also available to manage secondary, simultaneous tasks. However, this spare resource may be engaged by tasks demanding of greater processing resources (i.e., listening in noise). As such, the dual-task paradigm is advanced from the notion that performance on secondary, simultaneous tasks reflect cognitive resources consumed during primary task processing (Kahneman, 1973; Salthouse, 1985).

Performance on simultaneous, secondary tasks have been used to show that modern hearing aid processors help improve listener effort, despite showing differential effects on speech intelligibility. For example Sarampalis et al. (2009) employed a dual-task paradigm to measure the effects of a noise reduction algorithm on speech understanding in young healthy adult listeners with normal hearing. For the first experiment, listeners were presented with speech in noise, and were instructed to repeat and remember the sentence-final words of the SPIN test. Whilst there was no significant improvements in speech intelligibility, participants were able to recall more words from memory when listening in the condition with noise reduction than without. Even though participants provided a response for each trial, recall was better for target words relating to sentence context than without context. For the second experiment a similar group of participants were instructed to repeat sentences and respond to an onscreen stimulus simultaneously (probe reaction task). The results of this second experiment followed a similar pattern to the first. That is, whilst noise reduction made little positive impact on speech intelligibility, the participants' reaction times to the visual stimulus were faster during the most challenging SNR conditions with the noise processing algorithm than without. Therefore, whilst speech intelligibility may not be improved, hearing aid algorithms may help reduce demand for top-down control of speech perception so that more resources are available for simultaneous encoding of words in memory, or faster processing time (Sarampalis et al., 2009). Furthermore, the results across these two experiments indicate that listening effort can be evaluated by either one of the dual-task procedures used.

In a similar study, Downs (1982) compared aided and unaided speech discrimination in 23 hearing-impaired males aged between 29-68 years, using a dual-task paradigm. For the primary task, participants were engaged in the discrimination of single words in multi-talker babble. For the secondary task, participants' reaction time to a light probe was measured. The results from that experiment showed that speech discrimination scores were significantly improved with hearing aid use compared to no amplification. Furthermore, participants' average reaction time to the light probe when aided was significantly shorter (faster) compared to the unaided condition, suggesting that hearing impaired listeners use less effort trying to discriminate speech with a hearing aid than without.

Recently, dual-task procedures have been used to compare the effects of noise on auditory-visual speech understanding and listening effort in younger adults (Fraser et al.

2010); and to also compare the relative amount of effort expended by younger and older normal hearing adults listening to speech in noise (Anderson Gosselin & Gagne, in press). In the study by Anderson Gosselin and Gagne (in press) participants were required to recognize target sentence words from a choice of on-screen alternatives. The simultaneous secondary task involved identification of tactile pulse patterns. The tasks were performed separately and then concurrently to calculate the proportion of task costs. For the first experiment the background noise level was kept constant for both participant groups. In terms of accuracy for speech in noise, younger participants performed significantly better to the older adults. Furthermore, when performing both speech and tactile recognition tasks simultaneously, the relative dual-task costs were significantly greater for the older adults. Even when the noise levels were adjusted (improved SNR) for the older participants so that speech understanding performance was equated across both groups in the second experiment, dual-task costs remained significantly higher for the older adults. On this basis, it was hypothesised that older adults expend more listening effort compared to younger adults when attending to speech in noise, even when accuracy for speech understanding in noise is similar. However, it was difficult to determine if individual differences in listening effort were related to declines in audition or cognition as the older adults were screened for cognitive impairment and clinical hearing loss.

In a separate task, Anderson Gosselin and Gagne (in press) asked participants to individually assess their own degree of listening effort. Whilst a correlation was found between the subjective responses and single task performance (speech understanding), a correlation was not observed in the case of dual-task performance (speech and tactile pattern recognition). As such, the authors concluded that dual-task paradigms were suitable to objectively measure listener effort, and to confirm results of subjective assessments.

In summary, the dual-task paradigm has been used effectively to examine how speech understanding, and the amount of cognitive effort expended, varies with listener age, auditory acuity, background noise and context (Anderson Gosselin & Gagne, in press; Downs 1982;

Downs & Crum, 1987; Feuerstein, 1992; Fraser et al., 2010; Pichora-Fuller et al., 1995; Sarampalis et al., 2009). As such, it is expected that a dual-task paradigm will be conducive to the examination of firstly, the effects of the aging voice on speech understanding in older listeners with hearing loss in background noise; and secondly, to validate, or otherwise, the recent finding that older adults with hearing loss perceive listening to *other* older adult speakers more effortful compared to younger adult speakers (Wilding, 2010).

Statement of the Problem

With current population trends, the number of persons over the age of 65 with hearing loss will increase dramatically over the next 20 years (Ashley-Jones, 2009; Greville, 2005). Due to the growing proportion of this population with hearing loss, it is important to understand the challenges older adults experience during daily communication so that appropriate rehabilitation strategies can be developed.

Age-related hearing loss (“presbycusis”) reduces the audibility of frequencies important for speech understanding (Dubno & Dirks, 1989; Dubno, Dirks, & Schaefer, 1989; Hornsby & Ricketts, 2006). In addition to hearing loss at the auditory periphery, senescent changes also occur in central audition and cognitive functions important to speech understanding such as working memory (CHABA, 1989; Craikhouse & Salt, 1992; Kemper, 1992). Furthermore, declines in audition are likely to engage more cognitive processing resources to recover complex speech inputs, resulting in increased listening effort (Pichora-Fuller et al., 1995).

The speech of other talkers is a common background interference in everyday listening situations (Agus, Akeroyd, Noble, & Bhullar, 2009; Festen & Plomp, 1990). Background noise consisting of other speakers is likely to mask the speech signal both peripherally and centrally, and has been shown to be more detrimental to speech understanding in older adults (Helfer & Freyman, 2008; Souza & Turner, 1994). Even when speech understanding in background noise has been successful, older adults report that listening is more effortful in these conditions relative to less noisy conditions (Larsby et al., 2008).

A number of investigators have revealed declines in older adults’ perceptual abilities when speech is degraded by background noise, or distorted directly using spectral and, or temporal manipulation (Amos & Humes, 2007; Arlinger, 1990; Divenyi, et al., 2005; Gordon-Salant & Fitzgibbons, 1997; Humes, et al., 2007; Humes, et al., 1991; Schmitt & Moore, 1989; Schneider, Daneman, & Murphy, 2005; Sheldon, et al., 2008; Vaughan & Letowski,

1997. Little progress, however, has been made to evaluate the effects of naturally degraded speech of other older adults. As older adults with hearing loss are often engaged in conversational discourse with similar-aged peers it is important to evaluate what effects vocal aging may have on speech perception in this population.

Aging affects the mechanisms involved in the production of speech (Ramig et al., 2001; Verdonck-de Leeuw & Mahieu, 2004). The older adult voice typically consists of inherent noise, production errors (Ferrand, 2002; Harnsberger, et al., 2010; Linville, 1996; Ramig & Ringel, 1983; Verdonck-de Leeuw & Mahieu, 2004), and characteristics that overlap with those observed in speakers with dysarthria (Darley et al., 1969). As such, the attributes of older adult speech ultimately combine to create a natural distortion of the speech signal (Torre & Barlow, 2009). It was recently demonstrated that speaker age did not have a significant effect on speech understanding in older adults with hearing loss (Wilding, 2010). However, these results were obtained for sentences presented in quiet only. Furthermore, the participants of that study subjectively found listening to be more effortful when listening to speech of older adults compared to that of younger adults. The findings of the study by Wilding (2010) warrant further investigation and, in relation to perception of effort, validation using objective measures across listening conditions (including noise).

Gosselin & Gagne (2010) argue that listening effort in older adults can be objectively measured using a dual-task paradigm. Research to date suggests that the dual-task paradigm is an effective method to assess both speech understanding and the amount of cognitive effort expended, when listener age, auditory acuity, background noise and context vary (Anderson Gosselin & Gagne, in press; Downs etc; Feuerstein, 1992; Fraser et al., 2010; Pichora-Fuller et al., 1995; Sarampalis et al., 2009). It follows then that the effects of speaker age on speech understanding and listening effort in older adults may be examined further using a dual-task paradigm.

The following study aimed to: (1) examine the effects of speaker age (one younger adult speaker versus one older adult speaker) on speech understanding in of older adults with hearing loss in quiet and background noise , (2) to determine whether the cognitive demands of the task varied as a factor of speaker age, and (3) to determine if differences in speech understanding and listening effort were associated with individual differences in hearing loss or working memory capacity.

Hypotheses

Speech recognition – Based on the results of Wilding (2010), it is hypothesised that the percentage of target words correctly identified by older listeners with hearing loss will: (1) be equivalent for sentences presented by an older adult speaker and a younger adult speaker in quiet, but (2) be significantly lower for sentences presented by an older adult speaker compared to sentences presented by a younger adult speaker in noise; and (3) be significantly lower for sentences containing no semantic cues to the target word compared to sentences containing semantic cues.

Word recall – Based on the results of Wilding (2010), it is hypothesised that the percentage of key words recalled by older listeners with hearing loss will be: (4) significantly lower for sentences presented by the older adult speaker compared to sentences presented by the younger adult speaker, and (5) significantly lower when sentences contain no semantic cues to the target word compared to sentences containing semantic cues.

Methodology

Participants

Listeners

A total of 18 healthy adults, 9 men and 9 women, ranging in age from 65 to 85 years (m = 72.83, sd = 5.03) completed the test battery assembled for this study. Listeners were recruited from the University of Canterbury Speech & Hearing Clinic client database, and members of the local community. All listeners were native New Zealand English speakers with a minimum of 10 years formal education.

All listeners had bilateral hearing losses of sensorineural origin as determined by audiological evaluation. Thresholds were measured at octave intervals between 250-8000 Hz for air conduction, and between 500-4000 Hz for bone conduction. The average air conduction thresholds of the left ear and right ear combined are displayed for each listener in Figure 1. To participate, listeners required a minimum hearing loss of 25 dB HL averaged across the frequency range 500 to 4000 Hz in the poorer hearing ear (Cruickshanks, et al., 1998). Furthermore, the hearing loss averaged over 500 to 2000 Hz did not exceed 50 dB HL for either ear, and did not differ by more than 19 dB HL interaurally (Jerger, et al., 1989).

Audiological evaluation was completed for each listener within six months prior to their participation in this study. Hearing assessment at the University of Canterbury campus was conducted using one of two GSI 61 two-channel audiometers (Grason-Stadler, Inc., Madison WI. USA), calibrated for use with Telephonics TDH-SDP supra-aural headphones and ER-3A insert earphones. Insert receivers were preferred unless contraindicated. Audiometers were calibrated for use with either a DX-C39 compact disc changer (Onkyo Corp, Japan) or a TFDVD1021 portable disc player (Dick Smith Electronics Ltd, NZ) to conduct speech audiometry.

Prior to audiological evaluation, listeners underwent Otoscopy and tympanometry. Listeners were required to have normal middle ear pressure and compliance (American Speech-Language-Hearing Association, 1990). Acoustic immittance was measured using a 226 Hz probe tone with descending ear canal pressure sweep rate of 200 daPa/s. Tymponometry was conducted with a GSI 33 Tympstar (Grason-Stradler, Inc., Madison WI. USA) or a Madsen OTOflex 100 device (GN Otometrics, DK). All Instruments used for audiological evaluation were calibrated to the manufacturer's specifications

A case history was also taken to exclude individuals with genetic or exogenous factors known to impair the auditory system including severe otologic disease, systemic disorders, head trauma, or symptoms associated with Ménière's disease including sudden hearing loss. Listeners exposed to occupational noise were admitted to the current study as census data from 1981 reported a sizeable proportion of the New Zealand workforce (45%) as being employed in "noisy" occupations (cf Greville, 2001). Furthermore, some listeners had previously served in compulsory military training.

Participants were required to be in good health with no history of stoke or neurological disease as evidenced by self report. All listeners tested negative for mild cognitive impairment as identified by the Montreal Cognitive Assessment (MoCA: Nasreddine et al., 2005). The MoCA consists of a thirty-point questionnaire and tests a variety of cognitive skills. The screen was administered and scored as per the instructions of Nasreddine (2004). Listeners required a minimum score of 26 out of 30. In addition, two participants recently fitted with hearing aids were admitted to the listening experiment – however, they did not wear their hearing aids during the assessment and had not worn them for at least 12 hours prior to its completion.

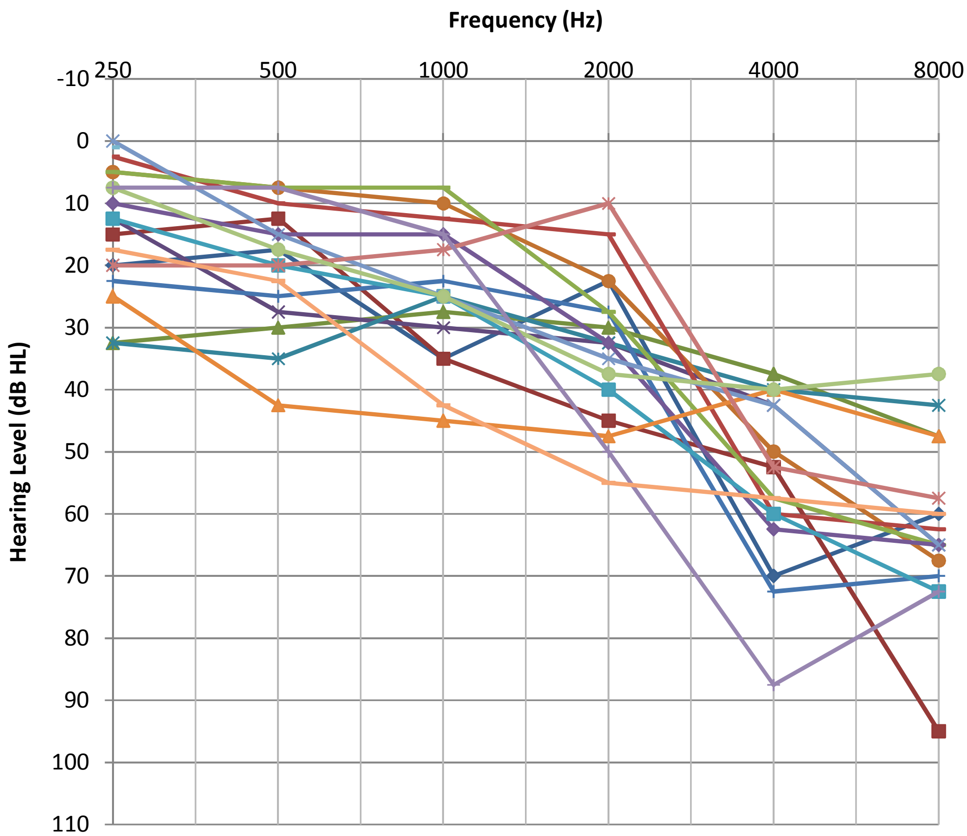

Figure 1. The air conduction thresholds averaged across both ears for each older adult listener participant.

Speakers: Experimental Speech Stimulus

One young adult male aged 23 years and one older adult male aged 86 years were recruited to produce the speech stimulus used for the listening experiment. Both participants were speakers of native New Zealand English. Perceptually, neither speaker presented with a strong regional accent. The young adult was a post-graduate student at the University of Canterbury. The older adult lived independently in the local community. The hearing thresholds of each speaker were obtained using pure-tone audiometry (Figure 2). The young adult's hearing was essentially normal (e.g., Harrell, 2002). In contrast the older adult demonstrated a mild to severe sensorineural hearing loss for octave frequencies between 2000-8000 kHz. The presence of a hearing loss did not preclude the older speaker from participating in this study as speech production in the older adults is influenced by reductions in auditory feedback (Liss, et al., 1990). At the time of recording, neither speaker demonstrated an illness or respiratory dysfunction. Nor did speakers report a speech or neurological disorder likely to affect speech production.

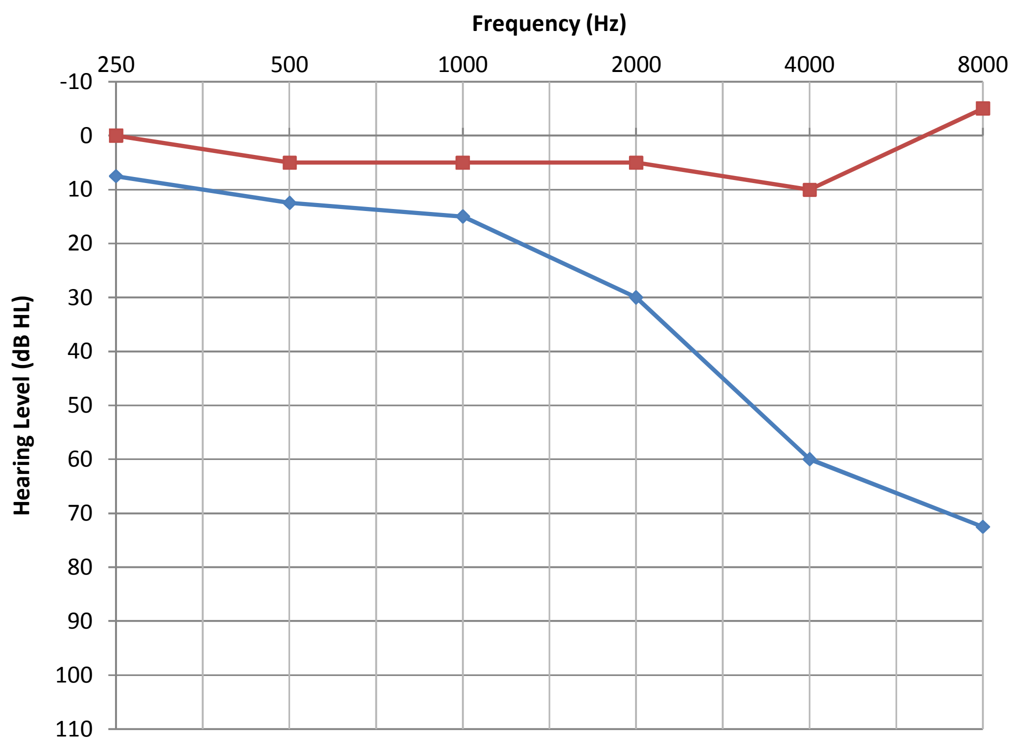

Figure 2. The air conduction thresholds averaged across both ears for the older adult speaker (filled diamonds) and the younger adult speaker (filled squares).

Speakers: *Composition of Six-talker Babble Stimulus*

Three males and three females between the ages of 21 and 49 years were recruited to produce the 6-talker babble used during the listening experiment. The male talkers involved in the babble recording were different from the two speakers who were involved in the composition of the experimental speech stimulus. All talkers were monolingual speakers of English, five of whom identified *New Zealand* English as their native language. The sixth speaker identified *British* English as their native language but had resided in New Zealand since early adolescence and, perceptually, exhibited a New Zealand English accent.

Stimulus Material

Sentence Material

In order to assess the effects of background noise and vocal aging on listener effort, the sentence lists of the speech perception in noise (SPIN) test (Kalikow, Stevens, & Elliott, 1977) were reproduced for use in this study. The SPIN materials consist of eight lists of 50 short sentences. Each sentence contains six to eight syllables. Within each list 25 sentences have contextual cues that make the sentence-final word highly predictable from preceding text (e.g., "*The farmer baled the hay*") while the other 25 sentences do not (e.g., "*Tom discussed the hay*").

All eight SPIN lists were recorded by both the older adult and young adult speaker during separate sessions of 1.5 hours duration. Recordings took place in a sound-attenuated booth in the Communication Disorders Research Laboratory at the University of Canterbury. Each speaker sat at a table and read aloud the sentences from printed text. They were instructed to speak in a relaxed, conversational manner and were given time to read each sentence prior to recording. Speakers were asked to repeat sentences containing lexical and / or grammatical errors, or hesitations. Each sentence was recorded as an individual file, therefore, participants were asked to introduce each sentence with the sentence list number, the sentence number, followed by a brief pause. Speakers were given opportunities to rest at the end of each sentence list. Recordings were completed using an HSP 4 condensor head level microphone and MZA 900P preamplifier combination (Sennheiser, Germany), coupled to a TASCAM HD-P2 portable stereo audio recorder (TEAC, Japan). The microphone port was kept at a distance of approximately six centimetres from the speaker's mouth, and recording levels were monitored in an effort to avoid peak clipping. The instantaneous amplitude of the audio signal was digitized directly to CompactFlash memory at a rate of 48 kHz with 16 bit accuracy. The final speech recordings were edited using Praat (Boersma & Weenick, 2010) to remove the non-sentence speech elements. The edited recordings were then catalogued according to sentence list and sentence number. An inverse filter process implemented in LabVIEW 8.20 (National Instruments, TX, USA) was used to ensure that all stimuli were at the same A-weighted dB sound level when presented through the InSync Buddy USB 6G soundcard and Sennheiser HD 280 supra-aural headphones used in the study.

Confirmation of Younger and Older Voicing Characteristics

A short perceptual rating session, that included two separate tasks, was conducted to confirm that the speakers chosen to represent the “older” and “younger” adult voices for the current study were indeed representative of these labels. Thirty-four undergraduate students enrolled in a first year acquired communication disorders paper heard a total of 25 sentences produced by both the older adult and younger adult speakers. Two sentences per speaker were chosen randomly from each of the first six SPIN lists. An additional sentence was selected from the young speaker to use as a practice item. The perceptual rating task was administered as an in-class activity and was completed on a voluntary basis. The stimuli were presented in a quiet lecture room via a public audio system. All responses were recorded in written format and transferred to a spreadsheet for analysis.

Of the 34 original participants in the rating task, data from nine was excluded. Therefore, final data analysis was completed on 25 students – 22 of whom were aged 18-25 years and the remaining three students aged 36-45 years. The responses of nine participants were excluded as: *New Zealand* English was not the first language for five students; responses were incomplete for three students; and one student did not comment on their presumed hearing status.

For task one, students were asked to judge the age of the older adult and younger adult speakers following each presentation of six sentences by both speakers. The mean perceived age of the older and younger adult speakers were calculated for each listener. The group mean and standard deviation across all listeners' responses were calculated to compare the perceived age of both speakers using a paired t-test. The results of the perceptual age task are shown in Figure 3. On average, the perceived age of the older and younger adult speakers was 60.9 years and 29 years respectively. As implied by visual inspection of this data, the difference in the perceived age between the older and younger adult speakers was statistically significant (t = 17.14, df = 48, p < .001).

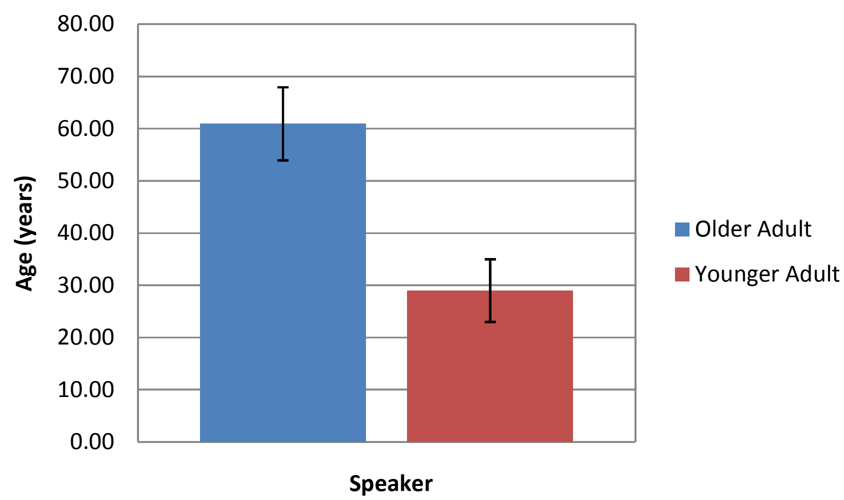

Figure 3. The perceived age the older adult speaker (left) and younger adult speaker (right). Group means are depicted by the filled bars, with vertical bars recording one standard deviation above and below the mean .

For task two, the students were asked to judge the remaining sentences based on characteristics of speech and voice that trained listeners have identified as salient cues to speaker age (Ryan & Burk, 1974). Specifically, these features were: *slow speaking rate,* *imprecise consonants, pitch, tremor / unsteadiness, and hoarseness / breathiness*. For each characteristic, the students were asked to provide an ordinal rating for each speaker – e.g., not applicable, mild, moderate, severe. Responses were summed for each ordinal rating to obtain the final proportions. To examine differences between the older and younger adult speakers, the relative proportions of each ordinal rating for every characteristic were calculated, and are displayed in Figure 4 to Figure 8. Statistical analysis was not completed as the ordinal ratings differed across each characteristic. Furthermore, ordinal ratings were either uni- or bi-directional. Instead, the descriptive results are discussed in turn.

The perceived speaking rate of the older adult and younger adult speakers is shown in Figure 4. Visual comparison of the data show that the older adult speaker tended to speak at a slower rate compared to the younger adult, consistent with previous research (Harnsberger, et al., 2010; Harnsberger, Shrivastav, Brown, Rothman, & Hollien, 2008; Ptacek & Sander, 1966; Ryan & Burk, 1974).

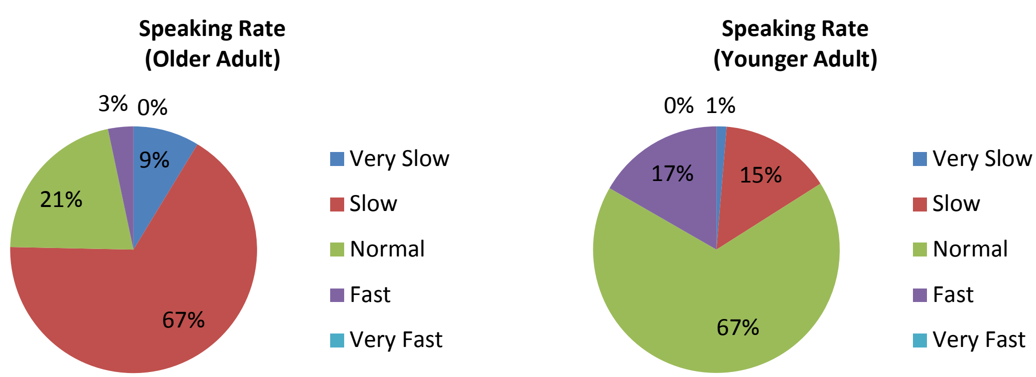

Figure 4. The perceived speaking rate for each speaker.

The proportion of imprecise consonants for the older adult and younger adult speakers is displayed in Figure 5. Inspection of the data show that the older adult speaker had a greater proportion of imprecise consonants than the younger adult speaker as expected from the results of earlier research (Ryan & Burk, 1974).

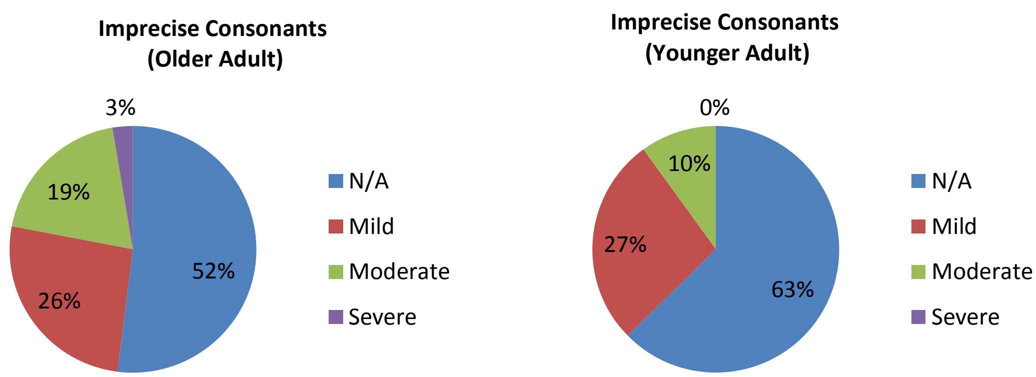

Figure 5. The proportion of perceived consonant errors produced by each speaker.

The perceived pitch of the older adult and younger adult speakers is shown in Figure 6. Most investigators have reported that the vocal pitch of males increases with age (Hollien & Shipp, 1972; Nishio & Niimi, 2008; Torre & Barlow, 2009). However, inspection of these figures show that the older adult speaker was perceived to have a lower vocal pitch than the younger adult. This pattern of decreasing pitch with increasing age was reported by Reubold, Harrington and Kleber, (2010).

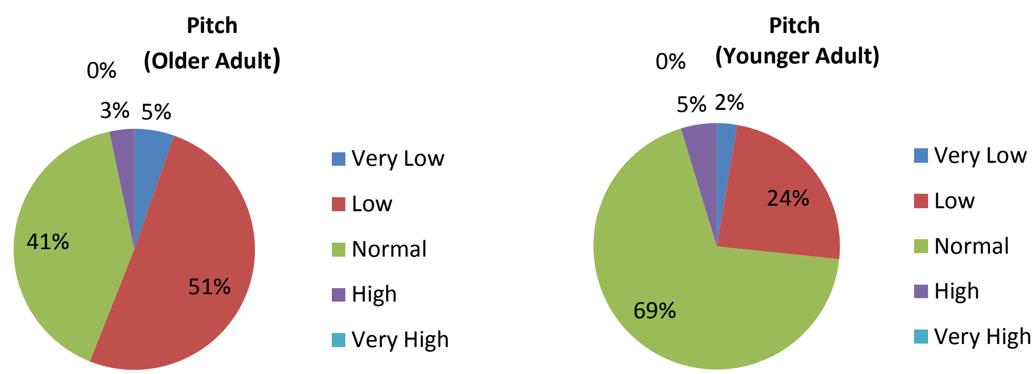

Figure 6. The perceived pitch for each speaker.

The amount of perceived tremor / unsteadiness in the voices of the older adult and younger adult speakers, as judged by the student participants, is shown in Figure 7. Inspection of these figures reveal that the older adult had a greater degree of perceived tremor / unsteadiness than the younger adult, consistent with the findings of Harnsberger et al. (2010).

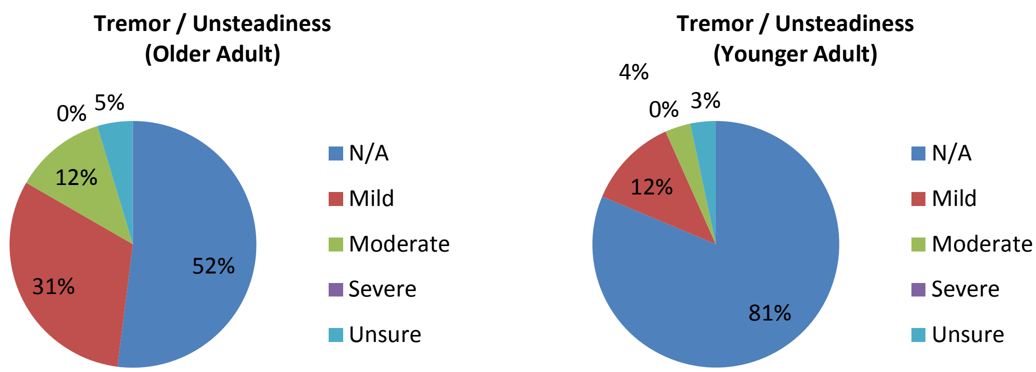

Figure 7. The amount of perceived tremor / unsteadiness for each speaker.

The amount of perceived hoarseness / breathiness in the voices of the older adult and younger adult speakers is shown in Figure 8. Inspection of these figures indicated that the older adult speaker had a greater amount of hoarseness / breathiness than the younger adult speaker. Breathy voice qualities are likely to differentiate older adults from younger adult speakers, although this attribute has been largely associated with the voice of older females (Gorham-Rowan & Laures-Gore, 2006; Linville, 2002).

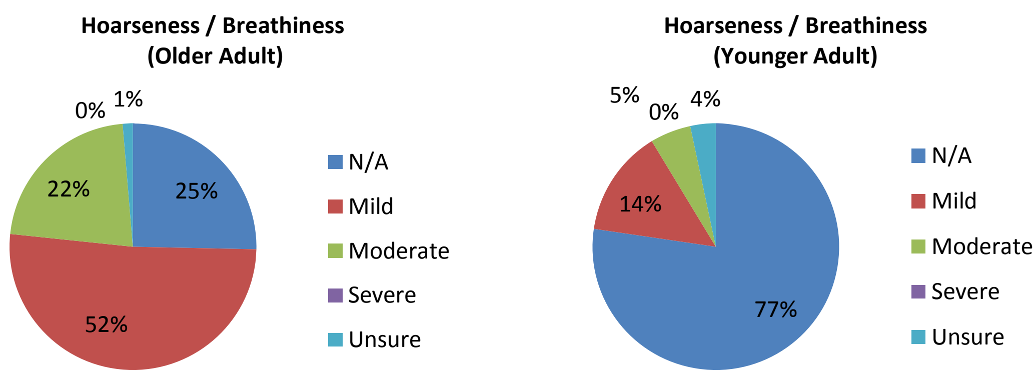

Figure 8. The degree of hoarseness / breathiness perceived for each speaker.

With the exception of pitch, the results of the remaining speech and voice characteristics assessed in the perceptual rating task here were in agreement with previous research. That is, the older adult spoke slower, produced more consonant errors, and had a perceived tremor and hoarseness in his voice, compared to the younger adult speaker. Combined with the fact that a difference in perceived speaker age was of statistical significance, these voice qualities demonstrate that each speaker was indeed representative of a younger adult and older adult.

Six-talker Babble Material

A six-talker babble was developed specifically for the current study. Six speakers read twenty semantically anomalous sentences (e.g., “Their stew was digging a curious bet”) developed by Smiljanic and Bradlow (2005). The anomalous sentences were six to 10 words in length and all sentences were recorded by the talkers recruited to produce the babble. Recording, editing, and equating the overall signal level (dB A) of these sentences followed the procedures outlined previously for the development of the stimulus material.

From these recordings, the 6-talker babble was produced on the fly by the University of Canterbury Perceptual Speech Ratings (UC-PSR: O’Beirne, 2010) computer software as follows: For each talker, silent intervals of varying length were added to the beginning the individual recordings. This jittering effect was used to minimise a perceived cadence once sentences from all talkers were mixed. The start of each individual file was then cut to ensure the babble would contain all 6 talkers. The 20 sentences recorded by each speaker were concatenated in a random order to avoid sentences being presented by more than one talker simultaneously. All six talkers were then mixed into a single sound file.

Procedures

Older adult listeners who met the audiological and cognitive criterion completed the experimental component of this study. This was divided into two main components described in detail below: (1) assessment of short-term and working memory, and (2) listening experiment. The order of memory tasks and the listening experiment were alternated across listeners. Listeners were tested individually in one of two sound treated rooms. The examiner was seated across a table from each listener for all test procedures.

Assessment of Working Memory

Working memory capacity was assess using the following subtests of the Weschler Memory Scale-Third Edition (WMS-III: Wechsler, 1997).

Digit Span (DS): — For the first part of this test, listeners were read a series of digits and were instructed to repeat the digits verbatim. For the second part, listeners were read a series of digits and were instructed to repeat the digits in the reverse order.

Letter-Number Sequencing (LNS): — The listener was read an alternating series of letters and numbers. The listener was instructed to repeat the digits in numerical order first followed by the letters in alphabetical order.

The DS and LNS tasks were chosen for this study due to their relatively light linguistic load, and their reliability as a survey of auditory memory abilities. Specifically, the sub-tests on the WMS-III including DS and LNS have internal consistency reliability coefficients between .74 and .93(Wechsler, 1997). Furthermore, performance on the LNS is an indicator of both working memory and attention according to Crowe (2000).

The administration and scoring of the DS and LNS sub-tests followed the WMS-III manual protocol (Wechsler, 1997), and the order of each subtest was alternated across listener participants.

Listener Effort Experiment

The listening experiment was administered and scored in a similar manner to the procedure used by Sarampalis et al. (2009). Briefly, the experimental speech stimuli were presented diotically. The participants were instructed to report the final word from each sentence as they heard it. Any deviation from the target word was scored as incorrect. Listeners were given frequent encouragement to guess. At the end of each sentence the stimulus paused automatically and the listener was given an opportunity to respond. Following a response, the examiner selected an onscreen icon to advance to the next sentence.

In addition to the word recognition task, listeners were instructed to commit each final word reported to memory. Following a set of 8 sentences, the examiner was cued by an onscreen message to prompt listeners to recall as many final-words as possible, in any order. Words that were misperceived during the primary speech understanding task but later recalled were scored as correct for the secondary task only.

Listening effort was measured using stimuli recorded by the older and younger adult speakers. The stimuli were heard in either quiet or in the presence of the six-talker babble developed for this study. The babble extended the length of the primary speech sentence, and was mixed with the stimulus material to achieve SNRs of either +5 dB or 0 dB. A SNR of +5 dB was chosen as this value has been reported to be the most conservative SNR encountered in a variety of everyday listening situations (e.g., Olsen, 1998). A more difficult SNR of 0 dB was chosen to further stress auditory processing abilities of older listeners with hearing loss.

The first six lists of the re-produced SPIN stimuli were used for the six experimental conditions: Speaker age (old or young) and six-talker babble (quiet, +5 dB or 0 dB SNR). The first 48 sentences were presented in their standard list order without repetition. Deletion of the final 2 sentences did not alter the balance of HP and LP items. To minimise ordering effects each sentence list, speaker, condition was heard an equal number of times across all serial positions. Furthermore, each list was presented in all condition combinations (i.e., speaker age and background condition) an equal number of times. Lists seven and eight of the SPIN were heard in quiet and served as practice items. This served to ensure listeners were familiar with: the task and required response; the voices of the older adult and younger adult speakers; and to ensure speech intelligibility in quiet at a sensation level comfortable for each listener. The presentation level of the stimulus material ranged from 70 to 77 dBA. A two-tailed student's t-test revealed no significant differences in the ability to recognise speech between the older and younger adult speaker presented in quiet for the pre-experimental items (t = 1.52.14, df = 15, $p > .05$)

The listening experiment was conducted using the University of Canterbury Perceptual Speech Ratings (UC-PSR: O'Beirne, 2010) computer software. Adjustable parameters meant the examiner could control stimulus delivery according to speaker age, SPIN list, background condition, and signal level. The UC-PSR software was run a Vostro 1510 laptop (Dell, US). The laptop, in turn, was coupled to the headphones via a Buddy USB 6G sound adaptor (InSync, Canada).

Administering the entire test battery in a single session took approximately 3 hours. Listeners were encouraged to complete testing over two sessions when audiometric testing was required. To further reduce the effects of fatigue, regular breaks and refreshments were also provided. Hearing aids or other assistive listening devices were not worn.

The older adult listeners, as well as the older and younger adult speakers, received a voucher to the monetary value of $10 for their contribution to this study. This study was approved by the University of Canterbury Human Ethics Committee. All participants were briefed prior to their involvement in this study and a signed consent form was received. Participants involved in the listening experiment were debriefed following completion of the entire test battery. Participants were free to withdraw from this study at any time.

Statistical Analysis

All responses for the recognition and recall tasks were recorded directly to a written score sheet. Each participant received an average score for the number of words correctly recognised and recalled for each listening condition. The data for each participant was collected in a Microsoft Excel spreadsheet and later transferred to PASW Statistics 18.0 for statistical analysis. The group means and standard deviations were compared for the speech understanding and word recall tasks using a three-way repeated measures ANOVA. As mentioned previously, the three independent variables assessed were: speaker age with two levels (young versus old), SNR with three levels (quiet, 0 dB and +5 dB SNR), and context with two levels (high versus low predictability). Sphericity of the repeated measures data was verified using Mauchly's test. A Pearson's product moment correlation was computed to assess the degree of linear relationship between the PTA calculated between 1.0-8.0 kHz, averaged across both ears, and the mean percentage of correct word recognition collapsed across all conditions. In addition, Pearson's product moment correlations were also undertaken to assess the degree of linear relationship between the raw scores attained on each of the DS and LNS tests, and the percentage of words correctly recalled collapsed across all conditions. A statistical significance level of 0.05 was adopted throughout.

Results

Speech Recognition Performance

The speech understanding performance data are displayed in Figure 9. The percentage of sentence-final words identified correctly is provided as a function of SNR, for high- and low-context sentences. The parameter is speaker age.

The repeated measures ANOVA of correct responses revealed three main effects. First, there was an expected effect of context, $F(1,17) = 440.17$, $p < .001$, $\eta_P^2 = .96$, such that performance for high-context sentences ($M_{HC} = 76.30$, $SE = 1.44$) was significantly better, than performance for low-context sentences ($M_{LC} = 55.07$, $SE = 1.94$). Second, there was a main effect of SNR, $F(2,17) = 423.20$, $p < .001$, $\eta_P^2 = .96$. Pairwise comparison with Bonferroni correction for multiple comparisons indicated significant differences across all levels (p<.001) such that speech understanding for the quiet condition ($M_Q = 95.37$, $SE = 0.88$) was significantly better than the +5 dB SNR condition ($M_{5\ dB} = 68.06$, $SE = 2.18$), which was significantly better than the 0 dB SNR condition ($M_{0\ dB} = 33.62$, $SE = 2.64$). Third, there was a main effect of speaker age $F(1,17) = 77.155$, $p < .001$, $\eta_P^2 = .82$ which revealed that speech understanding for the older speaker condition ($M_{Old} = 72.49$, $SE = 1.51$) was significantly better than the younger speaker condition ($M_{Young} = 58.87$, $SE = 2.06$).

The three two-way interactions were also significant. The interaction between context and SNR $F(2,34) = 33.34$, $p < .001$, $\eta_P^2 = .66$, suggested that the effects of context differed depending on the SNR. As demonstrated in Figure 9, speech understanding performance was better with high-context sentences than low-context sentences, particularly when the background babble was present. This was quantified through planned comparisons which tested the difference in words correctly identified for high and low context sentences at each of the SNRs. Results revealed that in the 0 dB SNR condition, the percentage of words correctly identified was significantly higher (p<.001) in sentences containing high-context sentences (M_{HC0dB} = 44.33, SE = 3.23) compared to low-context (M_{LC0dB} = 22.91, SE = 2.64). In the +5 dB SNR condition, the percentage of words correctly identified was also significantly higher (p<.001) in sentences containing high-context (M_{HC5dB} = 85.50, SE = 1.90) compared to low-context (M_{LC5dB} = 50.62, SE = 2.88). Again, in the quiet condition, the percentage of words correctly identified was significantly higher (p<.001) in sentences containing high-context (M_{HCQ} = 99.07, SE = .42) compared to low-context (M_{HC} = 91.66, SE = 1.66).

For the two-way interaction between speaker age and SNR, Mauchly's test indicated that the assumption of sphericity had been violated $\chi^2(2) = 7.18$, $p < .05$, hence, the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .74$). Corrected, the age x SNR interaction was significant $F(1.47,24.97) = 11.78$, $p < .01$, $\eta_P^2 = .41$. To further investigate this finding, three planned comparisons were undertaken to compare scores when listening to the young and older speakers at each of the SNRs. Results revealed in the 0 dB SNR condition, the percentage of words correctly identified was significantly higher (p <.001) when the sentences were produced by the older speaker (M_{0dBOld} = 41.08, SE = 2.79) compared to the younger speaker ($M_{0dBYoung}$ = 26.15, SE = 3.28). In the +5 dB SNR condition, the percentage of words correctly identified was also significantly higher (p<.001) when the sentences were produced by the older speaker (M_{5dBOld} = 79.18, SE = 2.46) compared to the younger speaker ($M_{5dBYoung}$ = 56.94, SE = 3.05). In quiet condition, the percentage of words correctly identified was significantly higher (p<.01) when the sentences were produced by the older speaker (M_{QOld} = 97.22, SE = .71) compared to the younger speaker (M_{0Young} = 93.52, SE = 1.27).

The two-way interaction between speaker age and context, $F(1,17) = 6.15$, $p < .05$, η_P^2 = .266, indicated that the effects of speaker age were different for the two types of context. Whilst speech understanding fell from high- to low-context sentences, performance was better with the older adult speaker compared to the younger adult speaker (Figure 9). To further investigate this finding, two planned comparisons were undertaken to compare scores when listening to the young and older speakers in each context. The results showed that for sentences containing low-context, the percentage of words correctly identified was significantly higher (p<.001) in the older speaker condition (M_{LOld} = 63.38, *SE* = 2.16) versus the younger speaker condition (M_{0dBYoung} = 46.76, *SE* = 2.42). Also, for sentences containing high-context, the percentage of words correctly identified was again significantly higher (p<.001) in the older speaker condition (M_{HOld} = 81.61, *SE* = 1.21) compared to the younger speaker (M_{HYoung} = 70.98, *SE* = 1.87).The three-way interaction was not significant.

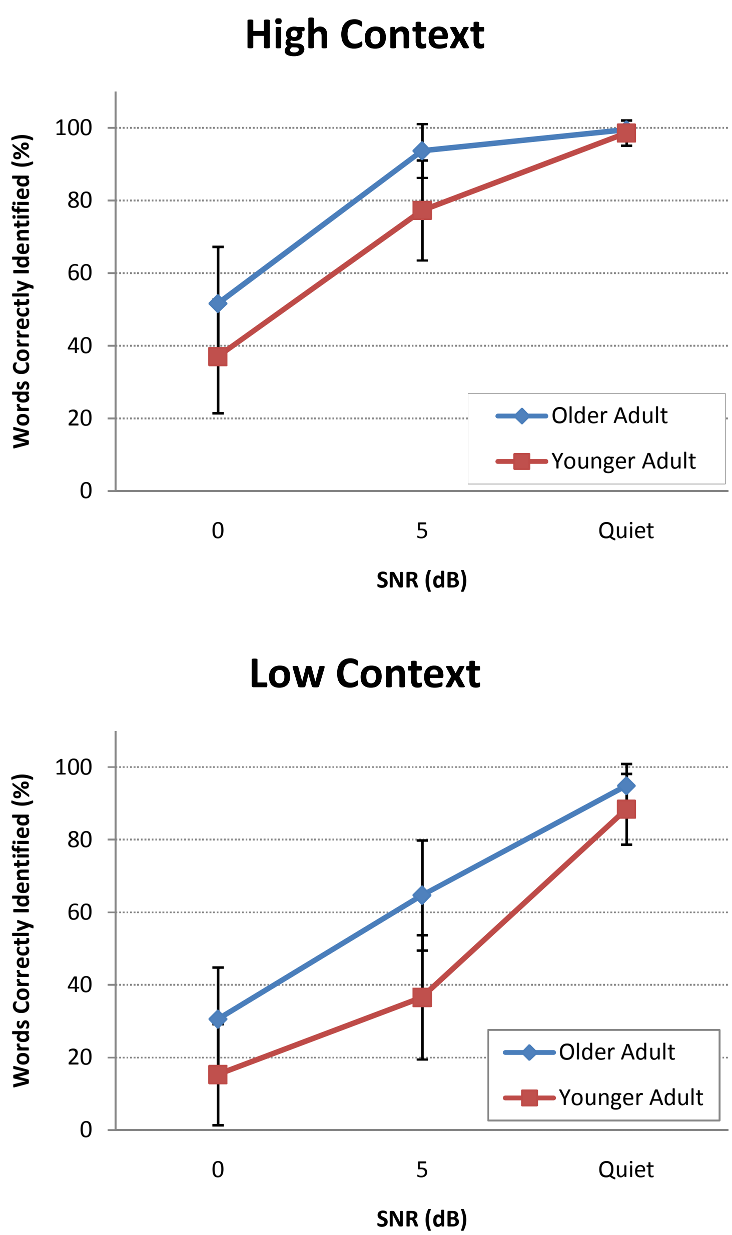

Figure 9. Speech recognition as a function of signal-to-noise ratio (SNR), averaged across 18 older adults with hearing loss. The top and bottom panels show performance for sentences with high context and low context respectively. Listeners' speech understanding results are plotted with regards to the age of the speaker. Error bars denote 1 standard deviation.

Word Recall Performance

The mean recall performance for sentence-final words as a function of SNR are displayed in Figure 10. The graphs are arranged as in Figure 9.

The repeated measures ANOVA of final word recall revealed three main effects. First, there was an expected effect of SNR, $F(2,34) = 40.30$, $p < .001$, $\eta_P^2 = .70$. Pairwise comparison with Bonferroni correction for multiple comparisons indicated significant differences across all SNR levels ($p < .01$) such that word recall for the quiet condition (M_Q = 39.17, SE = 1.52) was significantly better than the +5 dB SNR condition ($M_{5\ dB}$ = 34.33, SE = 1.74), which was significantly better than the 0 dB SNR condition ($M_{0\ dB}$ = 23.96, SE = 2.16). Second, there was a main effect of context, $F(2,17) = 34.23$, $p < .001$, $\eta_P^2 = .67$ such that recall for final words was significantly better with the high-context sentences (M_{HC} = 36.30, SE = 1.63) compared to the low-context sentences (M_{LC} = 28.67, SE = 1.70). Third, there was a main effect of speaker age $F(1,17) = 7.53$, $p < .05$, $\eta_P^2 = .31$ which revealed that recall for final words was significantly better with for the older speaker condition (M_{Old}= 33.65, SE = 1.52) compared to the younger speaker condition (M_{Young} = 31.32, SE = 1.65). The two and three-way interactions were not significant.

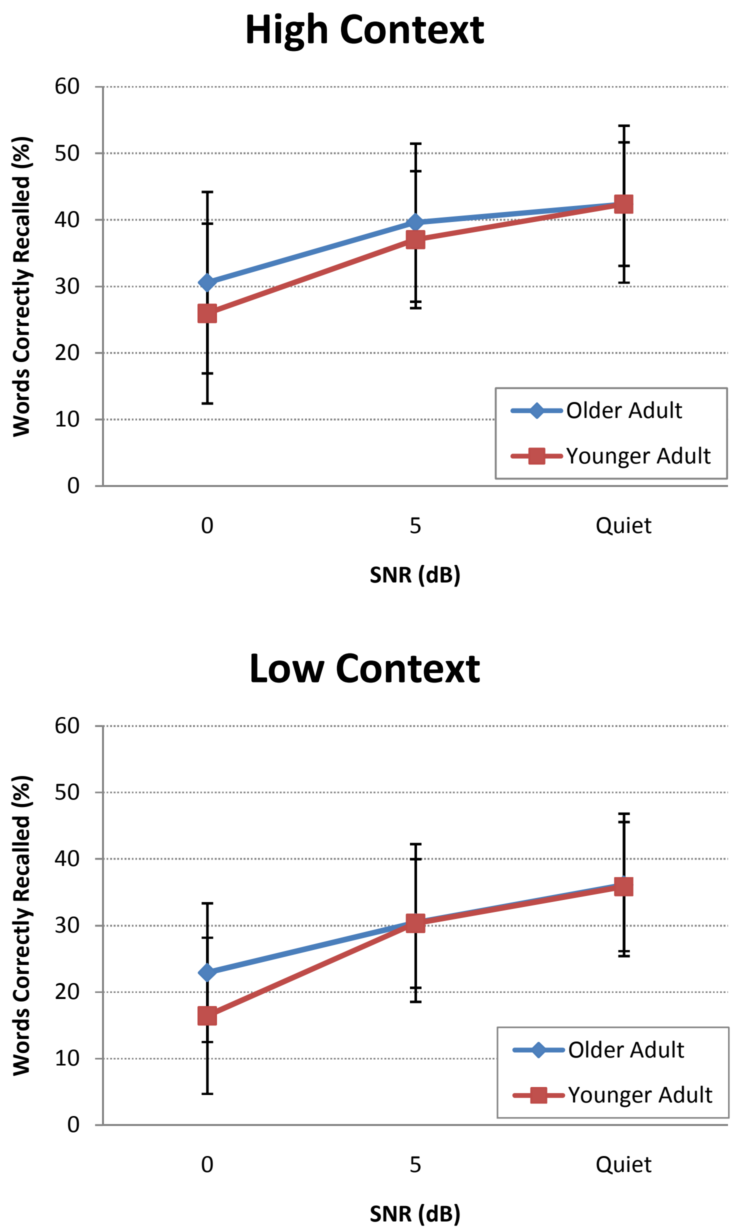

Figure 10. Word recall as a function of signal-to-noise ratio (SNR), averaged across 18 older adults with hearing loss. The top and bottom panels show performance for sentences having contextual information and for sentences without contextual information, respectively. Data obtained with the older speaker are plotted with filled diamonds, and data obtained with the younger speaker are plotted with the filled squares. Error bars denote 1 standard deviation.

Correlation Analysis

The degree of linear relationship between dual-task measures, hearing loss, performance on working-memory task measures, and age are shown in Table 1.

Table 1. The Pearson product-moment correlation coefficients for data pooled across all listener participants (** = statistical significance at the .01 level (2-tailed); * = statistical significance at the .05 level (2-tailed).

	LNS	DS	PTA 1-8 kHz	Words identified	Words Recalled	Age
LNS	—	.325	.139	.384	.475*	-.425
DS		—	.030	.203	.437	.004
PTA 1-8 kHz			—	-.554*	-.365	.409
Words Identified				—	.594**	-.785**
Words Recalled					—	-.515*
Age						—

A moderate negative relationship, that was statistically significant, was found between the average percentage of words identified and pure-tone hearing loss. This indicated that listeners' ability to identify words declined with increasing hearing loss. Correlation analysis revealed little, if any relationship between speech understanding and DS, and a low correlation between speech understanding and LNS. This suggested that listeners' ability to identify words was not associated with auditory working memory scores. Finally, a correlation analysis between the average percentage of words identified and age revealed a strong, negative correlation between these variables. This indicated that the ability to identify target words declined with increasing age and was statistically significant Individual performance on the primary task (words identified) also plotted against hearing loss, working-memory scores, and age in Appendix IV.

The correlation analysis revealed a weak, negative relationship between the average percentage of words recalled and hearing loss. This relationship between these variables was not statistically significant suggesting that the ability to recall words from memory was not associated with hearing loss. The correlation between average word recall and DS score did not reach statistical significance, however, a weak but statistically significant correlation was reached between word recall LNS. Hence, the ability to recall words was shown to have a small, positive association with working memory. Finally, a negative correlation of moderate degree was found between the average percentage of words recalled and age. This relationship was statistically significant indicating that word recall declined with increasing age. Individual performance on the secondary task (words recalled) are plotted against hearing loss, working-memory scores, and age in Appendix V.

Discussion

The aim of the current investigation was to examine the effects of speaker age on speech understanding and listening effort in older adults with hearing loss. It was proposed listeners would exhibit significantly reduced speech understanding and significantly greater listening effort when listening to the speech of an older, as opposed to a younger speaker. A dual-task paradigm was implemented to explore these hypotheses. A secondary aim of the investigation was to determine whether individual differences in speech understanding and listening effort were associated with differences in degree of hearing loss or differences in performance on tasks of working memory. Overall, four main findings were observed: (1) listeners' speech understanding scores were significantly higher when listening to the speech of the older as opposed to younger speaker, (2) listeners' scores for recall of words from memory were significantly higher when listening to the speech of the older adult compared to the younger adult, (3) individual differences in speech understanding were negatively associated with age and hearing loss, while (4) individual differences in listening effort were negatively associated with age and positively correlated with working memory performance. The following discussion will address these findings with regard to the speech understanding results, the word recall results and the correlation analysis.

Primary-Task Findings – Objective Measures of Speech Understanding

Analysis of the primary-task data revealed a significant effect of speaker age on speech understanding in the older adult participants with hearing loss. In contrast to the hypotheses, listener participants demonstrated improved speech understanding when listening to the older adult speaker compared to the younger adult speaker. Senescent changes in the speech and voice of older adults are posited to compromise speech clarity (e.g. Torre & Barlow, 2009). Based on previous results, it was expected that speech understanding in the older participants with hearing loss would be similar when listening to the younger adult speaker and the older adult speaker in quiet. However, it was hypothesised that differences in noise would emerge, and older adults with hearing loss would achieve significantly higher speech understanding scores when listening to the younger adult, compared to the older adult speaker. This assumption was reasonable as the speech stimuli produced by the older speaker recruited for this study was judged perceptually by adults from the general population as hoarse, breathy and unsteady. Furthermore, comparison of the perceptual data for each speaker indicated that the older adult was identified as having more production errors compared to the younger adult speaker. Two factors or a combination of these, may have contributed in the current findings.

Firstly, inspection of the perceptual rating task data indicated that, perceptually, the speech rate of the older speaker was slower than that of the young speaker. In light of the current results, the slower rate evidenced by the older speaker may have allowed listener participants sufficient time to integrate successive speech inputs, and distinguish the primary signal from the background babble; hence, aiding speech understanding. Evidence for a slowing speech processing mechanism with increasing age supports this view (Tun, Wingfield, Stine & Mecsas et al., 1992). However, previous research has shown that speech signals slowed artificially (Schmitt, 1983; Gordon-Salant & Fitzgibbons, 1997) or naturally (Schmitt & Moore, 1989), compared to ‘normal’, offer only a modest improvement in speech understanding in older adults with hearing loss.

Secondly, the older speaker communicated to the examiner that he was in good health, lived independently, and was an active member of the community. Whilst data from the perceptual rating task reveals distinct differences between the older adult and younger adult speaker, the mean age of the older speaker was perceived to be more than 25 years his junior. As inherent noise levels in speech are typically greater among older men in relatively poor physical condition (Ramig & Ringel, 1983), it is possible that the older adult speaker did not possess the reductions in speech and voice quality necessary to produce the desired effect. Future studies assessing the effects of vocal aging on speech understanding in older adults should incorporate stimulus materials produced by speakers who are perceptually and acoustically representative of their age.

The effect of speaker age was consistent across high- and low-context sentences. On average, the difference between the older speaker and younger speaker was greatest for listener participants in the low-context condition. When sentence context is limited so that predictability of a sentence-final word is low, listeners are forced to rely on available acoustic cues to correctly perceive speech (Kalikow et al., 1977). Inspection of the low-context data show that performance in noise falls more dramatically when the speaker is a younger adult. This could suggest that components of the younger adult speaker were more detrimental to speech understanding. For example, the perceptual rating data indicates that the younger speaker spoke at a ‘normal’ rate. However, the younger adult’s speech production rate was relatively faster in comparison to the older speaker. This faster speech rate of younger speaker may have compromised performance in the listener participants, even in quiet. As such, evidence exists to show that older adults experience significant reductions in speech understanding when the speech rate is increased (Gordon-Salant & Fitzgibbons, 1993; Schmitt, 1983; Schmitt & Moore, 1989; Tun et al., 1992).

Intonation effects may have also precluded the number of sentence-final words identified in the younger speaker condition. Anecdotally, the listener participants perceived a noticeable descent in the younger adult speaker’s voice toward the end of sentences. Whilst aspects of the older adult’s speech may have helped to improve performance, objective and perceptual findings suggest that the younger adult speaker was largely responsible for the differential effect observed in the older listener participants with hearing loss. Manipulation of younger adult speech so that speaking rate is shifted perceptually toward to that of older adult speakers may go some way in confirming this theory (e.g., Haarnsberger et al., 2008).

Secondary Task Performance – Objective Measures of Listener Effort

Analysis of the secondary-task data revealed that speaker age had a small but statistically significant effect on the ability to recall sentence-final words from memory. Overall, listener participants recalled more words when the speech stimuli were presented by the older adult speaker compared to the younger adult speaker. Once again, this outcome differed to the one hypothesised: it was expected that more cognitive resources would be concentrated toward recovery of the naturally distorted older adult speech, leaving less capacity for later recall of target words(e.g., Kahneman, 1973).

The results instead indicate that greater processing or attentional resources were allocated during speech understanding when the speaker was a younger adult. Whilst this observation may reflect the relatively faster speech rate of the younger adult as described earlier, Tun et al. (1992) reported that increased speech rate did not have significant differential effects on either accuracy for pictorial identification, or response latencies, when older listeners performed these tasks concurrently with speech understanding. The findings by Tun et al., however, were obtained in older listeners with clinically normal hearing who performed competing tasks in non-auditory modalities. In the current investigation, listeners had to decode the faster young adult speech through a degraded auditory system, and commit the translation of each word to memory while processing subsequent information.

To validate the effect of speaker age on ability to recall words from memory, a pre-experimental check was conducted to ensure that differences in recall ability was not due to differences in the ability to hear each speaker. The results of the pre-experimental check showed no significant difference in intelligibility for either speaker in quiet. This was again confirmed by the results attained in the listening experiment. Specifically, speech understanding in quiet reached ceiling levels when the stimulus materials were presented by either speaker. Thus, it can be interpreted that the older adults with hearing loss in this study engaged more processing or attentional resources (i.e., listening effort) to recognise target words spoken by the younger adult.

The objective findings reported here conflict with the results described by Wilding (2010). In that study, older participants subjectively found listening more effortful when the speaker was an older adult. Differences in methodology make it difficult to directly compare the results of both studies; however, as stated previously, subjective effort does not necessarily reflect the amount of cognitive resources needed to accomplish perceptual tasks (Anderson Gosselin & Gagne, in press; Fraser et al., 2010; Zekveld et al., 2010).

Background noise has the ability to mask the primary speech signal on a peripheral and central level (Hornsby, Ricketts & Johnson, 2006; Larsby et al., 2008), and has been demonstrated here to have greater adverse effects on speech understanding than the natural distortions of aged speech. It is not surprising then that participants' ability to recall target words from memory was positively related to increasing SNR. This finding is consistent with previous dual-task investigations reporting depressed scores for competing tasks when listeners are forced to recognise speech in background noise (Anderson Gosselin & Gagne, in press; Feuerstein, 1992; Fraser et al., 2010; Pichora-Fuller et al., 1995; Sarampalis, 2009). Whilst increased effort can support listeners to maintain speech understanding ability across different noise levels, particularly when complimented by visual cues (Fraser et al., 2010; Larsby et al., 2008); increased listening effort, as measured by secondary task performance for word recall, did not help participants in the current study achieve equivalent levels of speech understanding across the SNRs tested.

The results of the recall data also show that participants had better recall for words presented in sentences containing context. Whilst cognitive resources are engaged when supportive context is used to understand what is being said in complex listening conditions (Kalikow et al., 1977), these findings suggest that older listeners consume greater resources when listening to speech with reduced context (Pichora-Fuller et al., 1995; Sarampalis et al., 2009).

Correlational Findings – Primary-task Performance

The results from the correlation analysis revealed that individual differences in speech understanding were negatively associated with age and hearing loss. There was a moderate, but significant relationship between overall speech understanding performance and hearing loss. This finding differs to results of earlier studies that have described statistically strong, negative associations between speech understanding and high-frequency hearing thresholds (Cokely & Humes, 1992; Halling & Humes, 2000; Helfer & Wilber, 1990; Humes et al., 1994; Humes, Nelson & Pisoni, 1991; Humes & Roberts, 1990). When weaker relationships have been reported, these have typically been observed in studies employing sentence level materials, consistent with the current study (Cokely & Humes, 1992; Humes et al., 1994). The general pattern of results in the present investigation suggest that individuals with smaller degrees of hearing loss attain better speech understanding scores than those with greater degrees of high-frequency hearing. However, inspection of the relationship between these variables in Appendix IV demonstrates a range of performance scores between individuals with hearing loss of similar magnitude. As such, only 30.25% of the variation in speech understanding scores can be explained by individual differences in hearing acuity.

The primary observation from the correlation data was that age had a strong, negative relationship with speech understanding. According to this analysis, approximately 62% of the variation in speech understanding scores could be accounted for by age. As such, hearing loss alone was not the limiting factor among participants in this study. Other investigators have also suggested that age-related factors beyond hearing loss are likely to account for speech understanding difficulties in older adults during complex listening conditions (Gordon-Salant, 1987; Gordon-Salant & Fitzgibbons, 1997; Helfer & Wilbur, 1990).

Whilst previous studies have found a connection between individual tasks of working memory and speech perception performance in older adults (Humes & Floyd, 2005), these relationships are typically small and secondary to hearing loss (Akeroyd, 2008). Comparison of those with similar degrees of hearing loss in the present study demonstrate that individuals who performed more poorly on the speech understanding task also scored more poorly on the LNS task. However, this pattern of findings was not consistent. As such, the correlation analysis revealed weak positive relationships between performance in both DS and LNS with speech understanding. Whilst LNS scores may account for 14% of the differences observed in individual performance, no significant correlation between the primary-task and each of the working memory tasks was found.

Beyond age-related declines in working memory, other changes in cognitive performance such as reduced inhibition skills (Stewart & Wingfield, 2009) and changes in processing speed (Fraser et al., 2010; Tun et al., 1992) may have accounted for some of the individual differences in speech understanding performance. Furthermore, deficits in central auditory processing that accompany age (Chisolm et al. 2003) may have had an effect in this group of listener participants.

Correlational Analysis – Secondary-task Performance

Overall, findings from the correlation analysis conducted on the secondary task data suggest that individual differences in listening effort were negatively associated with age, and positively correlated with working memory performance.

An important result to emerge from the correlation analysis was that age had a significant relationship with the ability to remember words during a competing speech perception task. These results are consistent with those reported by Pichora-Fuller et al., (1994), and suggest that listening effort increases with age (Anderson Gosselin & Gagne, in press).

Both old and young listeners with reduced hearing sensitivity have demonstrated less capacity to store words in memory during perceptual processing (Murphy et al., 2000; Pichora-Fuller et al., 1994). Spare working-memory capacity used to temporarily store information may be lost to processing tasks where acoustic signals degraded by internal noise (Pichora-Fuller et al., 1995; McCoy et al., 2005). As such, reduced capacity to recall words, and thus increased listening effort, may be due to age-related declines in peripheral hearing. To examine this idea further a correlation analysis was performed between individual performance on word recall and hearing loss. Whilst the ability to recall words was shown to decline with hearing loss, this relationship was not significant.

Hence, other age–related factors such as reduced working memory may account for increased listening effort. If working memory capacity in older adults is already reduced in older adults (e.g., Humes & Floyd, 2005), then working memory in older listeners with hearing loss will be further limited due to additional processing requirements. It follows then that the ability to store and manipulate data in working memory, as measured by DS or LNS tasks, should be correlated with the ability to recall words from memory. In the current study, performance on the word recall task had a statistically significant relationship with performance on the LNS. Specifically, individuals who performed better on the LNS task were likely to do well on the secondary-task and recall more words from memory. This suggests that those who did well on the LNS had greater working memory capacity with which to store items for later recall. Interestingly, the variance in LNS scores is largely explained by performance on DS (Crowe, 2001). However, participants' scores on DS were neither highly correlated with scores attained on the LNS, or with overall word recall performance.

The correlation analysis between a number of factors and performance on the secondary-task revealed that the ability to recall words from memory was largely due to age and performance on a working memory task. On this occasion hearing loss did not play a significant role and would suggest that listening effort in older adults is largely due to declines in cognitive processes.

Clinical Implications

The rate of speech production is typically faster in younger adults compared to younger adults (Ryan, 1972). Furthermore, investigators have demonstrated that older adults with hearing loss perform disproportionately poorer compared to younger adults when the speech rate is increased (Gordon-Salant & Fitzgibbons, 1993; Schmitt & Moore, 1989; Schmitt, 1983). The results of the current investigation suggest that the younger speaker had a deleterious effect on speech understanding for older adults with hearing loss. While these results cannot be generalised to all young adults speakers instructing younger speakers to slow their rate of speech when communicating with older adults should help to improve speech understanding in the older population, if future studies yield similar findings.

It is well documented that factors beyond hearing loss are likely to contribute to the speech understanding abilities in older adults (Akeroyd, 2008; CHABA, 1988; Humes, 2007). The results of the correlation analyses indicate that when natural speech is presented in a variety of conditions, hearing loss accounts for a small degree of variation in the performance of older adults. Therefore, restoration of speech through amplification should not be considered as a means to an end in aural rehabilitation. However, improving the quality of the speech signal may help to alleviate cognitive effort in older adults when listening to speech in noise (e.g., Downs 1982; Sarampalis et al., 2009).

Limitations & Directions for Future Research

Interpretation of the results obtained from this experiment should be considered together with the limitations of the study. A sample size of 18 was used in this study. Whilst this is not a small number of participants, older adults represent a heterogeneous group as evidenced by performance on a variety of speech perception tasks (CHABA, 1988). As such, individual differences in speech understanding between the older adults in this study were large. A larger sample of older adults may help to strengthen the findings in relation to the effects of speaker age.

Only one older adult and one younger adult were recruited to produce the speech stimuli for this study. Furthermore, the speakers were male. Hence, it is difficult to generalise these findings to all adult speakers. Older adult women also demonstrate characteristics of speech and voice that enable listeners to differentiate them from younger female speakers (Gorham-Rowan & Laures-Gore 2006;Linville, 2002; Torre & Barlow, 2009). Perceptual and acoustic analyses of female speakers suggest that older women exhibit increased breathiness and hoarseness compared to younger women (Gorham-Rowan & Laures-Gore, 2006). Therefore, future studies measuring the effects of speaker age should also incorporate speech materials produced by greater numbers of speakers, including females.

It is important note that the speech perception materials used in the current study were those published by Kalikow et al. (1977). These SPIN lists have since been standardised by Bilger, Nuetzel, Rabinowitz, and Rzeczkowski, (1984). Use of the revised lists in older adults with hearing loss, however, is questionable owing to poor test-retest reliability (Cokely & Humes, 1992). Yet, the revised lists continue to be used for research purposes in this population (e.g., Gordon-Salant & Fitzgibbons, 1997; Pichora-Fuller et al., 1994; Sheldon et al., 2007).

Listener participants with the greatest hearing losses had poorer response rates during the primary task (speech understanding), particularly for the 0 dB condition. Whilst listeners were given frequent encouragement to guess the sentence-final word and often gave a response, word recall was found to be significantly correlated with word identification. Owing to both peripheral and central masking effects, listeners find it difficult to extract target speech in the presence of competing speech (Larsby et al., 2005). In noise, listeners typically understand speech better when complimented by visual cues (Fraser et al., 2010). As such, performance in the 0 dB SNR may have improved with visual cues. The use of auditory-visual cues would be a further ecological approach to assessing speech understanding in older adults. Alternatively, future studies should employ secondary tasks in a non-auditory stimulus modality if the ability to recall words from memory is compromised by the inability to detect the target stimulus.

The characteristics chosen for the perceptual rating task were those identified by trained listeners as cues to perceived speaker age (Ryan & Burke, 1974). However, naive listeners were used in the current study to make judgements on the speech and voice characteristics of the speaker participants. In the study by Gorham-Rowan & Laures-Gore (2006) the reliability of naïve listeners to assess selected speech and voice characteristics in both young and old speakers was low. Futhermore, their findings from the perceptual rating task did not relate well to the results of their acoustic analysis. Gorham-Rowe & Laures-Gore suggested that untrained listeners may find it difficult to judge certain aspects of speech and voice, hence, future studies employing different speaker age groups should aim to include an acoustic analysis of speech and voice that supports the perceptual data.

Finally, the older adult participants in this study anecdotally found the listening experiment demanding. To avoid fatigue effects the lists of materials and listening conditions were counter-balanced across participants. Each condition, however, was presented once without repetition. As such, measurement reliability is unknown. Furthermore, the data recorded to assess rater-reliabilty was incomplete.

Conclusion

In conclusion, the dual-task paradigm used in this study was sensitive to differences in the two speakers recruited for this study. Specifically, the older participants with hearing loss recognised less speech and expended more listening effort when listening to the young adult speaker. These results suggested that more cognitive resources were used when listening to the younger speaker such that later recall for words from memory was compromised more, than in the older speaker condition. Individual differences in speech understanding were negatively associated with age and hearing loss. Individual differences in listening effort were negatively associated with age and positively correlated with working memory performance. Overall, the findings provide further evidence that peripheral hearing loss is not the only contributor to speech understanding and word recall ability. The naturally occurring speech signal also has the potential to influence outcomes.

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Appendices

Appendix I

Human Ethics Committee approval letter, listener recruitment letter, listener information sheet, speaker information sheet, consent form, and debriefing form.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Ref: HEC 2010/74

11 June 2010

Geraldine Spencer
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Geraldine

The Human Ethics Committee advises that your research proposal "An objective measure of listening effort: effects of background noise and speaker age" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 4 June 2010.

It is suggested that the statement in the amended application following Question 6.4 regarding testing and hearing loss be fully incorporated into the listener group information sheet.

Best wishes for your project.

Yours sincerely

Dr Michael Grimshaw
Chair, Human Ethics Committee

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

19 Creyke Road
Ilam
Christchurch 8041

13 October 2010

«GreetingLine»

You are invited to participate in a research project titled: “An objective measure of listener effort: Effects of background noise and speaker age”. For this project we require a group of 20 to 30 people to participate in the study. Participants need to be aged over 65 years, have a hearing impairment, and be native speakers of New Zealand English. You may already have participated in a similar study conducted by Phillipa Wilding (Masters student) in 2009 – if so, we would be delighted if you could participate in this follow up study.

If you decide to volunteer for this study you will be required to complete the following tasks:

1. A full assessment of your hearing (**see note below*).
2. Cognitive Screen – Prior to completing the study tasks, we will administer a brief test that screens for mild cognitive impairment. You will be asked some questions such as “what day is it today?”
3. Listening task – you will be asked to listen to some short phrases from different speakers. Some of these sentences will be in quiet and some of them will be in noise. We will simply ask you to repeat back what you think you heard.
4. Additional cognitive task – you will be asked to listen to a sequence of random digits and then repeating back the digits in the same you hear them or in reverse order. As well, you will listen to a series of characters and be asked to place them in a certain order.

In total, your involvement in this study will take approximately 60 minutes. *However, if your hearing has not been fully assessed within the last 12 months, this will require an additional 60 minutes. All of the tests may be completed in one session, or over two sessions if you would prefer. The tests will be carried out at the University within the Department of Communication Disorders Research facility. You will receive a petrol voucher as compensation for your time. Participation is voluntary, and you are free to withdraw from the study at any stage.

Any information gathered will be kept strictly confidential, and you will in no way be able to be identified through the results of the study. This study has received ethical approval from the Human Ethics Committee at the University of Canterbury.

Thank you for your consideration. If you would like more information or are interested in participating in this study, please contact **Geraldine Spencer on 027 273 6403**, email: geraldine.spencer@pg.canterbury.ac.nz or Dr Megan McAuliffe on 364 2987 ext. 7075, email: megan.mcauliffe@canterbury.ac.nz.

Yours sincerely,

Geraldine Spencer
Masters of Audiology Student

Dr. Megan McAuliffe
Department of Communication Disorders & NZ Institute of Language, Brain & Behaviour

INFORMATION SHEET – LISTENER GROUP

1.05.10

<u>**Project Name:**</u> An objective measure of listening effort: Effects of speaker age and background noise

You are invited to take part in the research project titled: "An oobjective measure of listening effort: Effects of speaker age and background noise". Please take the time to read this information sheet thoroughly and consider whether you would like to participate. Your participation is entirely voluntary (your choice). The following research team is conducting this study:

<u>**Principal Investigator**</u>**:**
Geraldine Spencer, Masters of Audiology Student

<u>**Associate Investigators**</u>**:**
Dr Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr Natalie Rickard, Senior Lecturer, Department of Communication Disorders
Dr Greg O'Beirne, Senior Lecturer, Department of Communication Disorders

We are interested in how older people with hearing loss hear and understand speech in noise and how this relates to certain aspects of memory. An understanding of how well people with hearing loss can understand speech will be helpful for audiologists in the development of assessment and treatment plans.

You may already have participated in a similar study conducted by Phillipa Wilding (Masters student) in 2009 – if so, we would be delighted if you could participate in this follow up study. Prior to beginning the tasks, we will administer a brief test that screens for mild cognitive impairment. You will be asked some questions such as "what day is it today?" We may also need to reassess your hearing. Your ears will be examined, then earphones will be placed in your ears through which you will hear some beeps. You will be asked to press a button whenever a beep is heard. This will provide information on the degree and configuration of your hearing loss which is important for the study. Following this, the function of your middle ear and inner ear will be assessed by placing an earphone in each ear separately and recording measurements via a computer. You may feel a slight change in pressure, but this test does not require you to respond. The hearing assessment will be administered by a Masters of Audiology student in the soundproof testing booth at the Department of Communication Disorders. It is expected that this will take approximately 60 minutes. Should the results of your hearing assessment show an unexpected hearing loss, this will be discussed with you.

Once the hearing test has been completed, you will be asked to undertake the following tasks:

(1) *Listening task:* Earphones or headphones will be fitted onto your head. You will hear sentences spoken by different speakers. Some of these sentences will be in quiet and some of them will be in noise. We will simply ask you to repeat back what you think you heard.
(2). Additional c*ognitive task:* You will be asked to listen to a sequence of random digits and then repeating back the digits in the same you hear

them or in reverse order. As well, you will listen to a series of characters and be asked to place them in a certain order.

In total, your involvement in this study will take approximately 60 minutes. However, if you hearing has not been fully assessed within the last 12 months, this will require an additional 60 minutes. All of the tests may be completed in one session or the testing may be conducted over two sessions if you prefer.

CONFIDENTIALITY

- Your privacy and confidentiality will be maintained at all times.
- All information will be kept in a locked filing cabinet at the Department of Communication Disorders, University of Canterbury. Only the researchers or research assistants involved in the project will have access to this information.
- The results of this project will be published; however, no material which could personally identify you will be used in any reports on this study.
- Feedback on individual assessment results will be provided at the time of testing.
- If you wish you will be advised of the results of the study.
- The research team may need to access your previous audiological clinical records, for which your consent will be required.

COMPENSATION FOR PARTICIPATION

You will receive a $10 petrol voucher for your participation in this study.

RISKS OF PARTICIPATION

There are no physical risks to participating in this project. Due to the length of the sessions you could become tired and will be given as many breaks as you feel necessary. If any of the tasks become too difficult or stressful the testing will discontinue. If you feel uncomfortable or unable to continue at any time you can withdraw from the study.

LOCATION

The hearing assessment will be conducted at the Department of Communication Disorders Speech and Hearing Clinic. The listening tasks, cognitive and auditory processing assessments will take place at the research laboratory at Room 801, Level 8, Rutherford Building, University of Canterbury (the Department of Communication Disorders research and postgraduate facility).

WITHDRAWING FROM THE STUDY

It is important to note that this study is voluntary and that you can withdraw from it at any time. This will in no way jeopardise any of your future dealings with the Department of Communication Disorders. If you choose to withdraw from the study, any data collected prior to withdrawal will not be used for research purposes without your consent.

ETHICS

This study has received ethical approval from the Human Ethics Committee at the University of Canterbury. Please do not hesitate to contact Dr McAuliffe if you have any concerns regarding your participation in this project (see contact details below). If you would like to speak with someone not involved in the study, please contact the Secretary of the Human Ethics Committee, University of Canterbury, Registry, Level 6.

FOR MORE INFORMATION

Should you have further questions regarding the research, please feel free to contact Geraldine Spencer on 027 273 6403 or email geraldine.spencer@pg.canterbury.ac.nz. Alternatively, Dr Megan McAuliffe on 364 2987 ext. 7075 or email megan.mcauliffe@canterbury.ac.nz.

INFORMATION SHEET – SPEAKER GROUP
1.05.2010

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Project Name:

You are invited to take part in the research project titled: "An objective measure of listener effort: Effects of background noise and speaker age. Please take the time to read this information sheet thoroughly and consider whether you would like to participate. Your participation is entirely voluntary (your choice). The following research team is conducting this study:

Principal Investigator:
Geraldine Spencer, Masters of Audiology Student

Associate Investigators:
Dr Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr Natalie Rickard, Senior Lecturer, Department of Communication Disorders
Dr Greg O'Beirne, Senior Lecturer, Department of Communication Disorders

This study looks at peoples' ability to recognise spoken language and perform a simultaneous word memory task. You will be asked to provide samples of your speech that will be used as part of a speech recognition experiment with older adult listeners who have a hearing loss. In an earlier study, older listeners with hearing loss reported that they find listening to noisey speech more effortful. The purpose of this follow up study is to measure listener effort objectively using speech recognition and word memory tasks. An understanding of how well people with hearing loss can understand speech will be helpful for audiologists in the development of treatment plans.

(1) You will be asked to read lists of short phrases. They will be analysed by a group of speech-language therapy students for specific perceptual features (e.g., pitch, loudness, speech rate) and will then be presented to the listeners during the experimental phase. At this stage about 30 older people with hearing loss will hear your recorded phrases. Your participation will be required for one session of approximately 60 minutes. The recordings will be made on a stand alone recording system using a microphone in a noise-reduced room at the location noted below. There will be no identifying information included in the recording other than your age group.

CONFIDENTIALITY

- Your privacy and confidentiality will be maintained at all times.
- All information will be kept in a locked filing cabinet at the Department of Communication Disorders, University of Canterbury. Only the researchers or research assistants involved in the project will have access to this information.
- The results of this project will be published; however, no material which could personally identify you will be used in any reports on this study.
- If you wish, you will be advised of the results of the study.

COMPENSATION FOR PARTICIPATION
You will receive a $10 petrol voucher for your participation in this study.

RISKS OF PARTICIPATION
There are no physical risks to participating in this project. However, if you feel uncomfortable or unable to
continue at any time you can withdraw from the study.

LOCATION
The recording of speech samples will take place at the research laboratory at Room 801, Level 8, Rutherford Building, University of Canterbury (the Department of Communication Disorders research and postgraduate facility).

WITHDRAWING FROM THE STUDY
It is important to note that this study is voluntary and that you can withdraw from it at any time. This will in no way jeopardise any of your future dealings with the Department of Communication Disorders. If you choose to withdraw from the study, any data collected prior to withdrawal will not be used for research purposes without your consent.

ETHICS
This study has received ethical approval from the Human Ethics Committee at the University of Canterbury. Please do not hesitate to contact Dr McAuliffe if you have any concerns regarding your participation in this project (see contact details below). If you would like to speak with someone not involved in the study, please contact the Secretary of the Human Ethics Committee, University of Canterbury, Registry, Level 6.

FOR MORE INFORMATION
Should you have further questions regarding the research, please feel free to contact Geraldine Spencer on 027 273 6403 or email geraldine.spencer@pg.canterbury.ac.nz. Alternatively, Dr Megan McAuliffe on 364 2987 ext. 7075 or email megan.mcauliffe@canterbury.ac.nz.

CONSENT FORM

Project Name: An objective measure of listening effort: Effects of background noise and speaker age

Principal Investigator:
Geraldine Spencer, Masters of Audiology Student

Associate Investigators:
Dr Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr Natalie Rickard, Senior Lecturer, Department of Communication Disorders
Dr Greg O'Beirne, Senior Lecturer, Department of Communication Disorders

- I have read and I understand the information sheet dated 1st May 2010 for volunteers taking part in the study designed to assess the speech recognition abilities of older adults with hearing loss.

- I have had the opportunity to discuss this study with the researcher/s. I am satisfied with the answers I have been given.

- I understand that my participation in this study is confidential and that no material that could identify me will be used in any reports on this study.

- I have had time to consider whether to take part.

- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time. I am also aware that this will in no way affect my future interactions with the Department of Communication Disorders.

I'm happy to be contacted for future studies	**YES/NO**
I consent to the results of these assessments being made available for future studies if required	**YES/NO**
I give permission to the research team to access my previous audiological clinical records from the University of Canterbury or, if from another clinic, please put the clinic name and address here:	**YES/NO**
I wish to receive a copy of the results	**YES/NO**

I hereby consent to take part in the study:

Name (please print): ____________________________

Signature: ____________________ Date: ____________________

Project Explained By: ____________________________

Project Role: ____________________________

Signature ____________________ Date: ____________________

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Date: ____________________

DEBRIEFING FORM

Project Name: An objective measure of listening effort: Effects of speaker age and background noise.

Principal Investigator:
Geraldine Spencer, Masters of Audiology Student

Associate Investigators:
Dr Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr Natalie Rickard, Senior Lecturer, Department of Communication Disorders
Dr Greg O'Beirne, Senior Lecturer, Deparment of Communication Disorders

Thank you for having participted in this study. The purpose of this research is to determine the effects of speaker age and background noise on listener effort in older adults with hearing loss. Listening effort is an important aspect of speech understanding. Whilst individuals with hearing loss may be able to recognise degraded speech they often say that it is effortful, or tiresome, to do so.

The information sheet that was given to before you participated in the study partly describes your role for the *listening task*. It was only when you began the task that you were made aware you had to repeat the target words and also ***memorise them for later recall***. The memory part of this task was not disclosed in the information sheet as this could have had a negative impact on your willingness to participate in this study. Alternatively it may have given you an opportunity to practice memorising speech phrases prior to your participation.

It has been shown in young adults with normal hearing that listening effort can be measured by their performance on a second, competing task such as memorising words. It has been proposed that when more effort is allocated to understanding older speech versus younger speech, fewer cogntive resources are available to perform other competing tasks. An understanding of how much effort older listeners with hearing loss use to recognise speech will be helpful for audiologists in the furture development of assessment and treatment plans.

We will be running this study over the next few months. We would ask you to maintain confidentiality about the procedures of this experiment since any pre-knowledge of the procedures will bias the data we obtain for subsequent participants (and therefore prohibit such data from our final analysis). If you are uncomfortable with not having being told about the memory component prior to the listening task, you you are free to withdraw from this study.

If you have any comments, concerns or questions regarding the research, please feel free to contact Geraldine Spencer on 027 273 6403 or email geraldine.spencer@pg.canterbury.ac.nz. Alternatively, Dr Megan McAuliffe on 364 2987 ext. 7075 or email megan.mcauliffe@canterbury.ac.nz. If you would prefer to speak with someone not involved in the study, please contact the Secretary of the Human Ethics Committee, University of Canterbury, Registry, Level 6.

Appendix II

A sample of the participant questionnaire for the perceptual rating task.

Project Name: An objective measure of listening effort: Effects of background noise and speaker age

Principal Investigator:
Geraldine Spencer, Masters of Audiology student

Perception of Voice Characteristics

Part 1

This is a speaker age estimation task.

You will hear a series of short phrases. At the end of each phrase, **please indicate what age you think the person speaking is.**

Number	**How old do you think this speaker is?**
Phrase 1	
Phrase 2	
Phrase 3	
Phrase 4	
Phrase 5	
Phrase 6	
Phrase 7	
Phrase 8	
Phrase 9	
Phrase 10	
Phrase 11	
Phrase 12	

Part 2

This is a perceptual rating task of voice characteristics.

You will hear phrases spoken by English speaking adults of different age. Each phrase will be repeated.

For each voice parameter (i.e., Speaking Rate, Imprecise consonants, Pitch, Tremor, & Breathiness / Hoarseness), **please indicate the degree of perceived deviance from normal using a circle**.

Practice

Speaking Rate	very slow	slow	normal	fast	very fast
Imprecise Consonants	N/A	Mild	Moderate	Severe	
Pitch	very low	low	normal	high	very high
Tremor (Unsteadiness)	N/A	Mild	Moderate	Severe	Unsure
Hoarseness / Breathiness	N/A	Mild	Moderate	Severe	Unsure

Phrase # (12 items)

Speaking Rate	very slow	slow	normal	fast	very fast
Imprecise Consonants	N/A	Mild	Moderate	Severe	
Pitch	very low	low	normal	high	very high
Tremor (Unsteadiness)	N/A	Mild	Moderate	Severe	Unsure
Hoarseness / Breathiness	N/A	Mild	Moderate	Severe	Unsure

Please take the time to complete the following details.

circle all applicable:

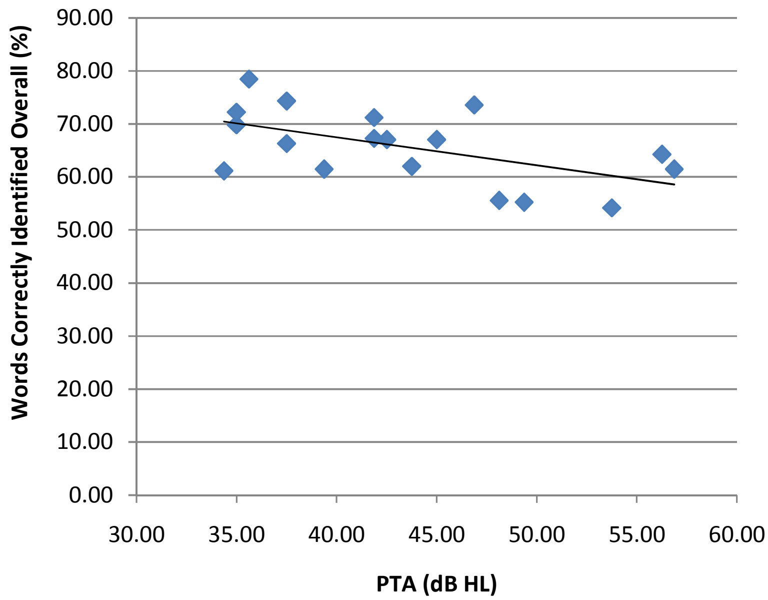
What is your age group:	**18–25**	**26-35**	**36-45**	**45+**	
What is your University Major	**BA / BSc / BSLT intermediate / Other**				
Which ethnic group do you belong to:	**NZ European**	**Maori**	**Other:**	___________	
What University year are you in:	**1st**	**2nd**	**3rd**	**4th (Hons)**	**Post Grad**
What is your native language:	**NZ English**	**Non-NZ Englsih**	**Maori**		
	Other:	________________________________			
Do you have a hearing loss:	**Yes**	**No**	**Unsure**		

Appendix III

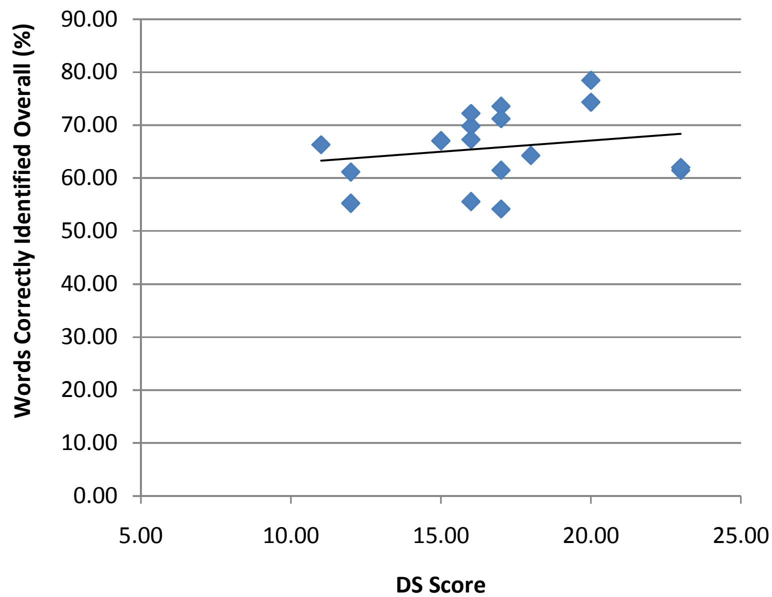
Individual participant raw scores achieved on the working-memory tasks DS and LNS.

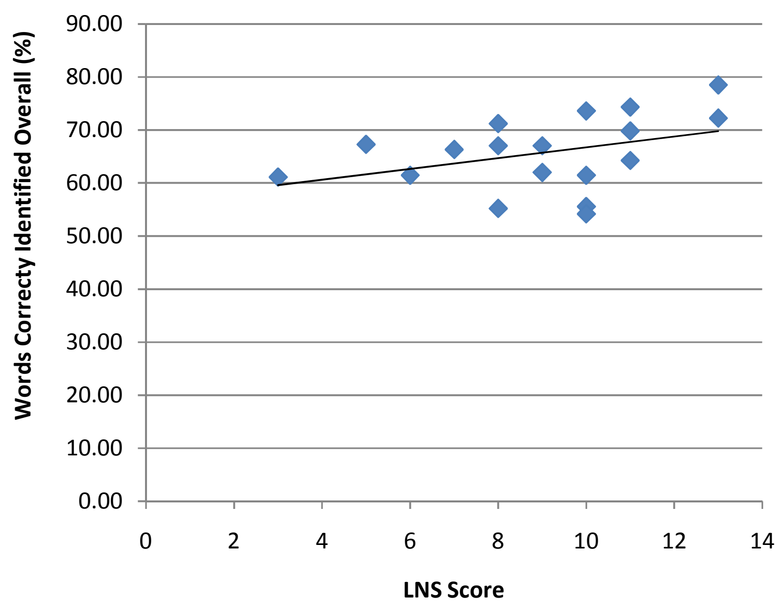
Participant	DS	LNS
1	17	10
2	17	10
3	20	13
4	15	8
5	16	11
6	11	7
7	16	10
8	20	11
9	23	6
10	23	9
11	12	8
12	15	9
13	12	3
14	16	5
15	16	13
16	18	11
17	17	8
18	17	10

Appendix IV

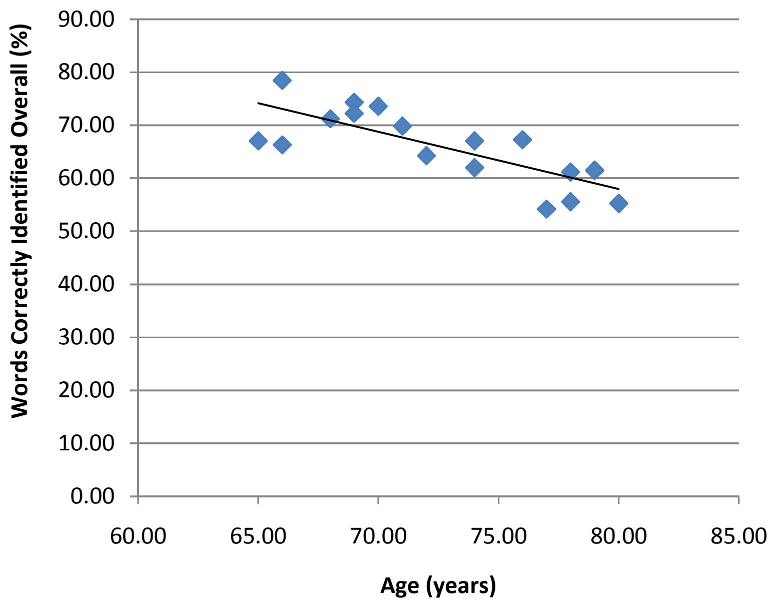


The pure-tone threshold average (PTA) from 1.0-8.0 kHz, averaged across both ears, versus the percentage of words correctly identified collapsed across all conditions.



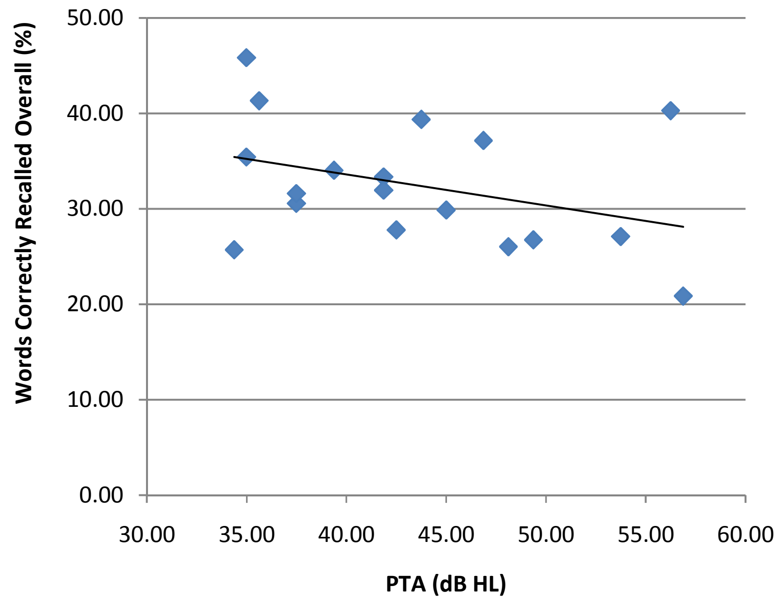


Combined raw scores attained on the forward and backward digit span task versus the percentage of words correctly identified collapsed across all conditions (top). Raw scores for the LNS task versus the percentage of words correctly identified collapsed across all conditions (bottom).

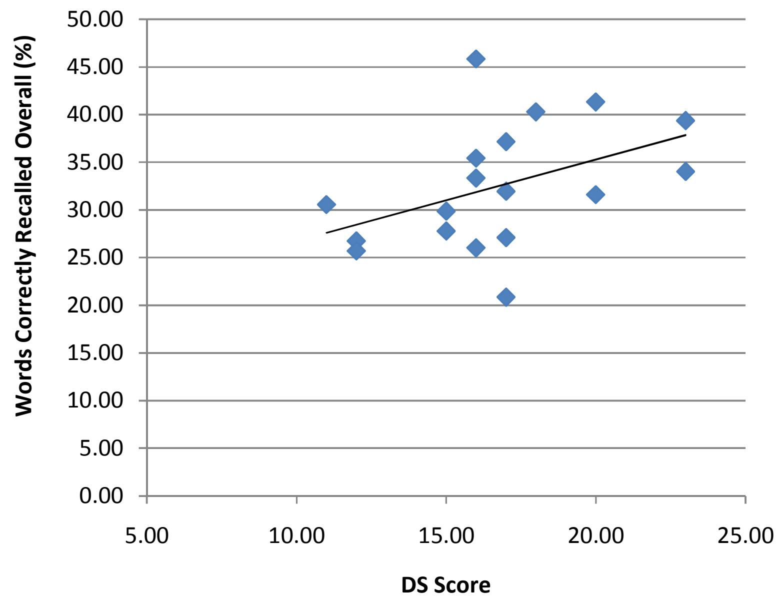


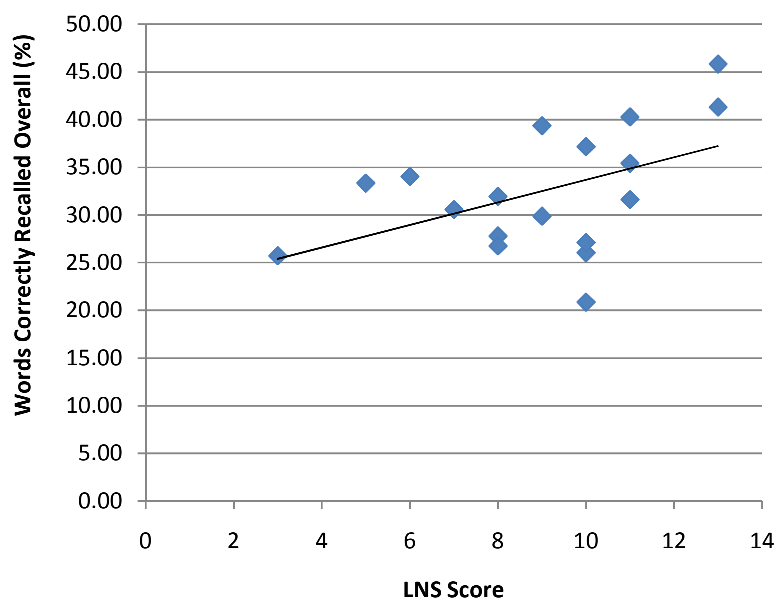
Age versus task versus the percentage of words correctly identified collapsed across all conditions.

Appendix V

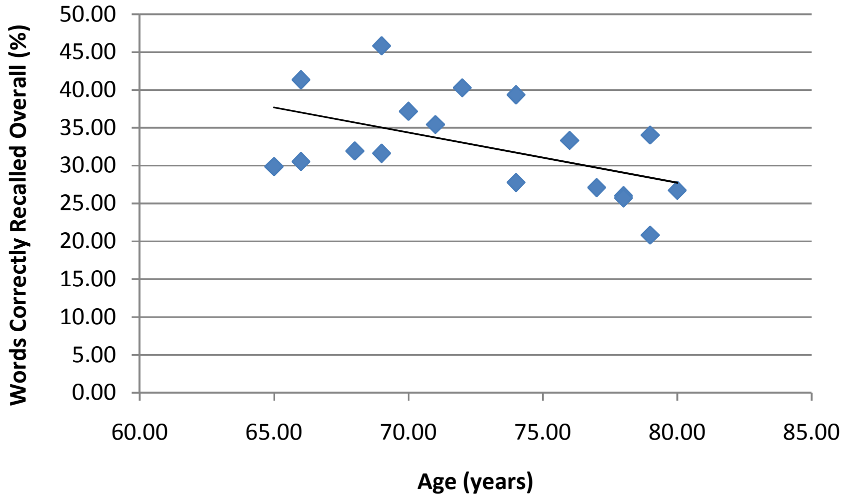


The pure-tone threshold average (PTA) from 1.0-8.0 kHz, averaged across both ears, versus the percentage of words correctly recalled collapsed across all conditions.





Combined raw scores attained on the forward and backward digit span task versus the percentage of words correctly recalled collapsed across all conditions (top). Raw scores for the LNS task versus the percentage of words correctly recalled collapsed across all conditions (bottom).



Age versus task versus the percentage of words correctly recalled collapsed across all conditions.